USING VFT AS A CONSTRAINT FOR GOAL PROGRAMMING MODELS: A CASE STUDY FOR TURKISH AIR FORCE FLYING HOUR PROGRAM

THESIS

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AFIT-OR-MS-ENS-12 -01

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Abstract

In its 60-year history, there are many published documents in the literature for goal programming (GP), but it is still open to some contribution. Hence, this research is looking for a goal-programming model to achieve this effort by discussing one of the key assumptions of GP about linearity, and some issues about incommensurability (difference in data types) and weighting while formulating the problems. In addition, GP requires an interaction between the decision maker (DM) and analyst to ensure that the model reflects the DM's preferences. However, it may be hard to interact if the mathematical model is very large and complex including many decision and deviation variables in it. Hence, we want a model that makes easier to interact with the DM while converting his/her qualitative values into quantitative ones and visualize them to the DM.

Consequently, this research comes up with the idea of using value focused thinking (VFT) in order to overcome the issues mentioned in the previous paragraph by using it as a constraint in GP formulations. The use of the model is demonstrated by a case study, "Turkish Air Force Flying Hour Program", which is a multi criteria optimization problem. It starts with utilizing the benefits of VFT in order to specify the values of the decision maker for a given multi objective decision problem, and then moves it forward into a multi criteria decision making problem as a constraint and finds the optimality conditions. The results obtained show the computational performance, efficiency, and robustness of the methodology.

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To my Wife, Expected Son, Mother and Father

Acknowledgements

First, I would like to thank to my country, the Republic of Turkey, the great Turkish Nation, and the Turkish Air Force for providing me this education opportunity. In the first years of the young Turkish Republic, Mustafa Kemal Ataturk, the founder of the Republic of Turkey, told to the students who were going to abroad to take education in a variety of fields “We are sending you as a spark, but you are going to come back as fire.” I hope I have achieved this.

I would like to express my sincere appreciation to my thesis advisor, Dr. Jeffery D.Weir, for his invaluable guidance, encouragement, and support throughout this thesis effort. I also want to thank to my reader Lt.Col. Ahner for his precious assistance and insightful comments.

Finally, I would like to thank to my wife for her support and love. I also want to thank to my family for their patience, support and encouragement throughout my life. I will not be the person that I am today if it were not the love and support of family.

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AAT	Air to Air Tasks
AGT	Air to Ground Tasks
AFLMA	Air Force Logistics Management Agency
AFT	Alternative Focused Thinking
DA	Decision Analysis
DAU	Defense Acquisition University
DM	Decision Maker
DOD	Department of Defense
ERP	Enterprise Resource Planning
GP	Goal Programming
JSF	Joint Strike Fighter
LP	Linear Programming
MCDA	Multicriteria Decision Analysis
MODA	Multiobjective Decision Analysis
NT	Night Tasks
OT	Other Tasks
PBL	Performance Based Logistics
PBA	Performance Based Agreements
PM	Program Manager
SDVF	Single Dimensional Value Function
SCM	Supply Chain Management
SME	Subject Matter of Expert

S&RL	Sense and Respond Logistics
TurAF	Turkish Air Force
USAF	United States Air Force
VBA	Visual Basic for Applications
VFT	Value Focused Thinking

USING VFT AS A CONSTRAINT FOR GOAL PROGRAMMING MODELS:

A CASE STUDY FOR TURKISH AIR FORCE FLYING HOUR PROGRAM

I. Introduction

1.1 Background

> To let GP fade away would be a tragic opportunity loss and can be avoided by using some marketing know-how. Product analyst know that a product life cycle can be shifted from a stage of decline to one of growth if something new is added to their products. After almost a thousand journal publications, can there be anything new to add to GP research? You can bet there is!
>
> Marc J. Schnierderjans (Schniederjans, 1995)

During World War I, Russia started to suffer from lack of goods to continue to the war, because German and Austria-Hungary Empire blocked Russia's trade routes on land, and no easy sea route existed to get help from the allies of Russia. The only sea route was the route from Mediterranean to Black Sea through Çanakkale (known as Gallipoli) and Istanbul straits that were controlled by Ottoman Empire. In 1915, Russia requested an aid from Britain to alleviate the pressure on it and open an efficient supply route to gain its power again. Britain agreed to give a response to this request by planning to conduct a combined naval and military operation on Çanakkale strait and Çanakkale Peninsula. This decision leaded to one of the most unforgettable battles to take place in the human history, called Battle of Çanakkale. In 1915, the naval operation was begun by the British Navy on February 16 and ended on March 18. It resulted in an unsuccessful attempt, which was followed by a decision to carry out a military operation on April

1915. This was also stopped by the Ottoman Army, lead by Lieutenant Colonel Mustafa Kemal, who later became Ataturk as the founder of Turkish Republic. After this event, the Allied Forces, consisting of British, French, Australian and Anzac troops, decided to abandon the campaign and withdrew their forces from the peninsula after having so many casualties. There had been several consequences of this remarkable battle that can be found in the literature, but one of the most important among all was bringing Imperial Russia to an end and leading it to Bolshevik revolution, a civil war in 1917 (Battle of Gallippoli, 2011). Although the approach and the strategy for military operations have changed a lot since we left a century behind, still there are numerous lessons that can be derived from this battle in terms of military operations. Among all the most evident ones is the importance of logistics in cases of a war which can change an empire's life as well as the world's future.

Although there are numerous definitions of Logistics on both the business side and the military side when we focus on the military side and search for it in the literature, United States Air Force Logistics Management Agency defines Logistics in two levels:

> At the intermediate level; Logistics is essentially moving, supplying, and maintaining military forces. It is basic to the ability of armies, fleets, and air forces to operate – indeed to exist. It involves men and materiel, transportation, quarters, depots, communications, evacuation and hospitalization, personnel replacements, service and administration. At a higher level, logistics is economics of warfare, including industrial mobilization; research and development; funding procurement; recruitment and training; testing; and in effect, practically everything related to military activities besides strategy and tactics (Air Force Logistics Management Agency, 2004).

However the definitions on logistics seem to lead us to the similar ideas about logistics, it is an improving term day by day according to the needs of a country. If we observe the United States as an example for this improvement, we may view this progress in three eras; the Traditional Logistics Era from the foundation of US until the Cold War ended, the Transition Logistics Era which occurred after the Cold War and consisting of variety of terms like Supply Chain Management (SCM), Sense and Respond Logistics (S&RL), Performance Based Logistics (PBL), and Enterprise Resource Planning (ERP) etc., and the Integrated Logistics Era which is considered as the future goal of US Department of Defense (DOD) (Buyukgural, 2009).

One of the most prominent ideas among these is the Performance Based Logistics, which is explained by Defense Acquisition University (DAU) as the DOD policy as:

> Performance Based Logistics (PBL) is the purchase of support as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapons system through long-term support arrangements with clear lines of authority and responsibility. Simply put, performance based strategies buy outcomes, not products or services (Defense Acquisition University (DAU), March 2005).

Although this approach of logistics has been implemented by USAF and by the other branches of US Armed Forces for years, Performance Based Logistics (PBL) came into play for Turkish Air Force as being a program partner of the F-35 Joint Strike Fighter Program since 11th of June 2002 (www.jsf.mil) as shown in Table 1.

Table 1 JSF Program Partnership (Schinasi, 2003)

Table 1: JSF Partner Financial Contributions and Estimated Aircraft Purchases

	System development and demonstration			Production	
Partner country	**Partner level**	**Financial contributions (in millions)[a]**	**Percentage of total costs**	**Projected quantities**	**Percentage of total quantities**
United Kingdom	Level I	$2,056	6.2	150	4.7
Italy	Level II	$1,028	3.1	131	4.1
Netherlands	Level II	$800	2.4	85	2.7
Turkey	Level III	$175	0.5	100	3.2
Australia	Level III	$144	0.4	100	3.2
Norway	Level III	$122	0.4	48	1.5
Denmark	Level III	$110	0.3	48	1.5
Canada	Level III	$100	0.3	60	1.9
Total partner		$4,535	13.7[b]	722	22.8
United States		$28,565	86.3	2,443	77.2

Sources: DOD and JSF program documents and AECA project certifications to Congress.

[a]Chart values do not reflect any nonfinancial contributions from partners (see app. II).

[b]Percentages do not add due to rounding.

Performance Based Logistics (PBL) has also many important key factors to be considered before implementing it into Turkish Air Force's (TurAF) current logistics system. One of these key factors in order to achieve a successful product support is the Performance Based Agreements (PBAs). According to the definition of Defense Acquisition University (DAU) about PBAs in their PBL Guide:

> PBAs establish the negotiated baseline of performance, and corresponding support necessary to achieve that performance, whether provided by commercial or organic support providers. The Program Manager (PM), using the performance objectives required by the warfighter, negotiates the required level of support to achieve the desired performance at a cost consistent with available support funding. Once the performance, support, and cost are accepted by the stakeholders, the PM enters into PBAs with users, which specify the level of operational support and performance required by the users: and into PBAs with the support providers, which specify the performance parameters that will meet the requirements of the warfighter (Defense Acquisition University (DAU), March 2005).

It can be seen from this definition, there are many parameters that should be considered and specified correctly before implementing this agreement in order to reach Air Forces' objectives with a cost effective product support. Since thinking in long-term agreements is a preferred approach while making PBAs, defining better required parameters means getting better results in terms of cost and product support. Regarding these considerations about PBL and PBAs, new approaches are going to be required in most of the areas after having this next generation strike aircraft in the Turkish Air Force (TurAF) as well as the logistics.

There is much research being carried out by the TurAF Headquarters depending upon these considerations about the upcoming next generation strike aircraft F-35 and its required revisions on the other fields. One of them arises from the possible need to redefine the flight requirements and optimizing the Air Force Flying Hour Program which is planned by the TurAF Headquarters according to the budget constraint and the official documentations (doctrines, guidelines, etc.).

The TurAF has a variety of aircraft (e.g. cargo, fighter, training, etc.) in its inventory. Other than these aircraft, many parameters make it complicated to prepare the flying hour program for the entire Air Force. There are different types of flight tasks (air to air tasks, air to ground tasks, etc.). These tasks can be accomplished by different types of squadrons (air to air squadrons, air to ground squadrons, etc.) These squadrons have different types of aircraft (F-4, F-16, C-130, etc.) requiring different numbers of flying hours with minimum and maximum values for pilots to be combat ready or to be current from different types of missions. Finally, there are multiple conflicting objectives like maximizing the TurAF’s combat readiness from each mission, while minimizing the cost. Therefore, when you think about this process with these parameters, it can be very complex for officials to optimize manually.

Military concepts were highly developed for the few past decades, and continuing to develop. There are lots of conceptual improvements in training, planning, programming, force structuring, etc. which are vitally important for all Armed Forces as well as the Air Forces itself. Therefore in addition to the considerations about the flying hour program stated in the previous paragraph, we need to include the decision maker's preferences into our model while preparing a flying hour program. A DM may wish to determine a combat readiness level represented by a value which he/she desires for the TurAF to be at at the end of that year by setting a goal in the beginning of the year. Also, the decision maker may wish to determine the importance level of required missions to be flown by squadrons and aircraft types giving some weights to differentiate them according to the inputs from different directorates in the headquarters (intelligence, research and development, etc.) every year considering the other Air Forces in the world.

In a given fiscal year, although the officials are able to prepare a good flying hour program for the entire Air Force it is evident that we should expect some possible shortages or overachievements than the predicted values depending on changes in some parameters. Hence, we expect our model also enables us to observe the deviations from the desired values that we want to achieve.

Considering all these aspirations, we would like our decision support model for TurAF Flying Hour Program to optimize the multiple objectives with a variety of constraints which meets the decision maker's preferences while considering the trade-offs. So, goal programming may best fit for modeling this problem. Goal programming is used for modeling multi criteria optimization problems where we have multiple conflicting objectives to achieve instead of a single objective as in linear programming, so in this manner we can say that it is an extension of linear programming (Schniederjans, 1995). According to Lee (1972), goal programming is used to deal with the decision situations with a single goal or multiple goals that have multiple sub-goals. In goal programming, we want to achieve these goals as closely as possible and the formulation infers that we may be penalized for the deviations from these aspiration levels (Charnes & Cooper, 1977); therefore the objective function deals only with minimizing these deviations that are the decision maker's major concerns in a given decision situation.

Schniederjans (1995) did a comprehensive review about goal programming in his book and claims that although there are many published documents in the literature for goal programming during its history, it is still open to some contribution to the existing ones. Hence, this research is looking for a goal programming model to achieve this effort.

For analysts to achieve a strong quantitative model for their decision situation by using goal programming, they need to interact with the decision maker to ensure that it reflects the decision maker's preferences. The decision maker should decide the desired goals in goal programming formulations, weight the deviation variables if we are using weighted goal programming, or prioritize the goals if we are using preemptive goal programming. There may be some problems between the analysts and the decision maker while interacting about this mathematical model especially if it is a very large and complex model. From an analyst stand point, it is good to be aware of the fact that most of the decision makers are more interested in the results than the mathematical backgound behind it (Dillon-Merrill, S., L., R., & J., 2008), but in this situation it is an obligation to include the decision maker in the process. Thus, we wish to create a model which makes it easier to interact with the decision maker while converting his/her qualitative values into a quantitative model and visualize them to the decision maker while overcoming some of the issues mentioned by Schniederjans (1995) in his text book about scaling and weighting related to goal programming model formulations.

Consequently, this research comes up with the idea of using value focused thinking in order to overcome the issues mentioned in the previous paragraph, and use it as a constraint in goal programming formulations. We claim that this approach may be used in any kind of decision situations that are similar to the problem presented as a case study in chapter 3, the Turkish Air Force Flying Hour Program. This approach starts with utilizing the benefits of Value Focused Thinking in order to specify the values of the decision maker for a given multi objective decision problem, and then moves it forward into a multicriteria decision making problem as a constraint.

1.2 Research Objectives, Assumptions, and Questions

The motivation of this research arises from the multi criteria optimization problem of Turkish Air Force Flying Hour Program. The current process is handled by the officials according to the documents (doctrines, guidelines, etc.) which are strict about what is to be done. It is difficult to make changes, and there is no optimization technique used for the problem. In addition, the decision maker's preferences are not included in the process except for some specific mission types, which may prevent the TurAF from keeping up with the other Air Forces in the world. However, this specific problem gave us the overall idea for this research which is examined as an application in chapter 3; we are looking for a methodology which can be generalized for similar multi criteria decision making problems.

This methodology requires the following assumptions to be made to be applicable in similar problems:

- The decision problem is eligible to construct a value hierarchy representing the decision maker's values,
- The data is suitable to create single dimensional value functions (SDVF) for the value hierarchy,

The research Question:

Is there any way to create a robust, effective and efficient Decision Support Method optimizing multiple conflicting objectives while satisfying goals at the desired levels including the Decision Maker's value structure and preferences?

In relation to the main research question, we are seeking answers to the following questions:

- Is there a need for this method?
- Is it possible to utilize some properties of VFT for a Goal Programming Model?
- Does the decision support methodology allow multiple decision makers to be involved in the problem?
- Does the method allow the decision maker and the stakeholders to understand the objectives, assumptions, and the mechanism of the problem?

1.3 Organization

Chapter 2 details decision analysis, value focused thinking and goal programming. Chapter 3 describes the methodology created for this research as a combination of VFT and Goal Programming. Chapter 4 shows an example for an application of the methodology developed in chapter 3 as a case study and the analysis of the results that are obtained from the implementation of the methodology. We use the TurAF Flying Hour Program, a real world problem, from which a need occurred to implement as a multi criteria optimization problem. Chapter 5 states recommendations and conclusions of this research and future work.

II. Literature Review

In this chapter, we define a decision, give the foundations of decision analysis, value focused thinking and goal programming, and then finally the research contribution.

2.1 Decision Analysis

A decision can be defined as a choice among alternatives which have uncertainties and involve decision makers' preferences in it (Howard, 2003). These three aspects of a decision situation can be illustrated as in Figure 1. The three legs of the stool constitute the basis of a decision where what you can do stands for the alternatives in the decision situation, what you know is the information you have, and what you want is the preferences of the decision maker(s). We can use these aspects in any decision situation where we have all of them at the same time, if one of them is missing then we cannot talk about a decision anymore. Also important is the frame of the decision situation where we place the stool. The decision maker should clarify the boundaries of the decision situation in order to implement these correctly. For example, the difference of the decision of buying a new car as a used one or a brand new one completely changes our decision situation and affects the decision basis.

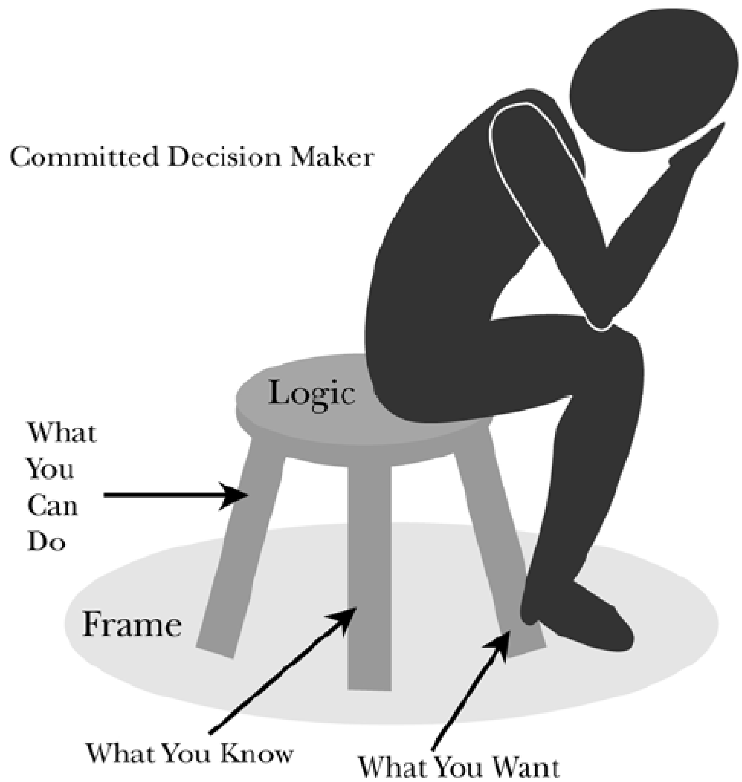


Figure 1 Decision Essentials (Howard, 2003)

A decision is an irrevocable allocation of resources (Robbins, 2010). Regarding this definition decision making is an extremely important and a difficult process for decision makers to handle. There are many reasons that cause difficulties to the decision situation, but we can define them under four main factors (Clemen & Reilly, 2001).

- Complexity; in a decision situation there are many individual issues which should be considered, and it is hard to keep all of them in mind at the same time.
- Uncertainty; it is impossible to know the outcomes of each alternative in a decision situation, and this lack of knowledge makes the decision hard.

- Multiple objectives; most of the real world decision situations have more than one objective which are often conflicting. The obligation of making trade-offs between these conflicting objectives is a difficult decision.
- Different perspectives; when we have multiple decision makers involved in the decision situation, there may be disagreements on the uncertainties, or they may have different preferences.

Considering all the difficulties stated above, we need an approach to convert them into a simple structure that can be analyzed and helps the decision maker(s) achieve the clarity of action which is called Decision Analysis. According to Howard (1981) Decision Analysis (DA) is used to specify the alternatives, information, and preferences of the decision maker(s) and then find the logically implied decision. Decision Analysis not only provides a better analysis for a decision situation but also it enables easy communication among the people involved in the process when you think of the difficulties of it (Howard, 1981).

Besides the benefits that Decision Analysis provides it also has some limitations which are important to keep in mind while implementing it to a decision situation. One of the most important among all is not to forget it is an approximation that it is used only to give insight about the decision situation to the Decision Maker(s) (Kimbrough, 2002). So, the Decision Maker(s) should make the decision considering other aspects which are beyond the analysis such as political or ethical implications (LaPietra, 2003). That is one of the reasons that the decision maker should be involved in a DA process, because the

DM’s values about the decision problem are the key elements for the analysis (Knighton, 1998).

2.2 Value Focused Thinking (VFT)

Value Focused Thinking (VFT) is a methodology that is used to solve Multiobjective Decision Analysis (MODA) problems where the decision maker’s values are fundamentally important. There are two approaches defined for problem solving in decision analysis methodology: Alternative Focused Thinking (AFT) which does not allow us to control the decision situation, and Value Focused Thinking (VFT) which enables us to control it (Keeney, 1992). In AFT the decision maker generally chooses the best alternative in a prespecified set of alternatives, so thinking about the values of the decision maker in AFT takes place after the alternatives are identified in a given decision situation which limits our way of thinking about the other possible alternatives that might be better but not included in the set. However, in VFT the decision maker’s values are taken as the key point and take the first place in a decision situation. Then we create alternatives with regard to the decision maker’s values and evaluate them in the same manner. Therefore, we can state that thinking about the values is the core point in VFT as shown in Figure 2 (Keeney, 1992).

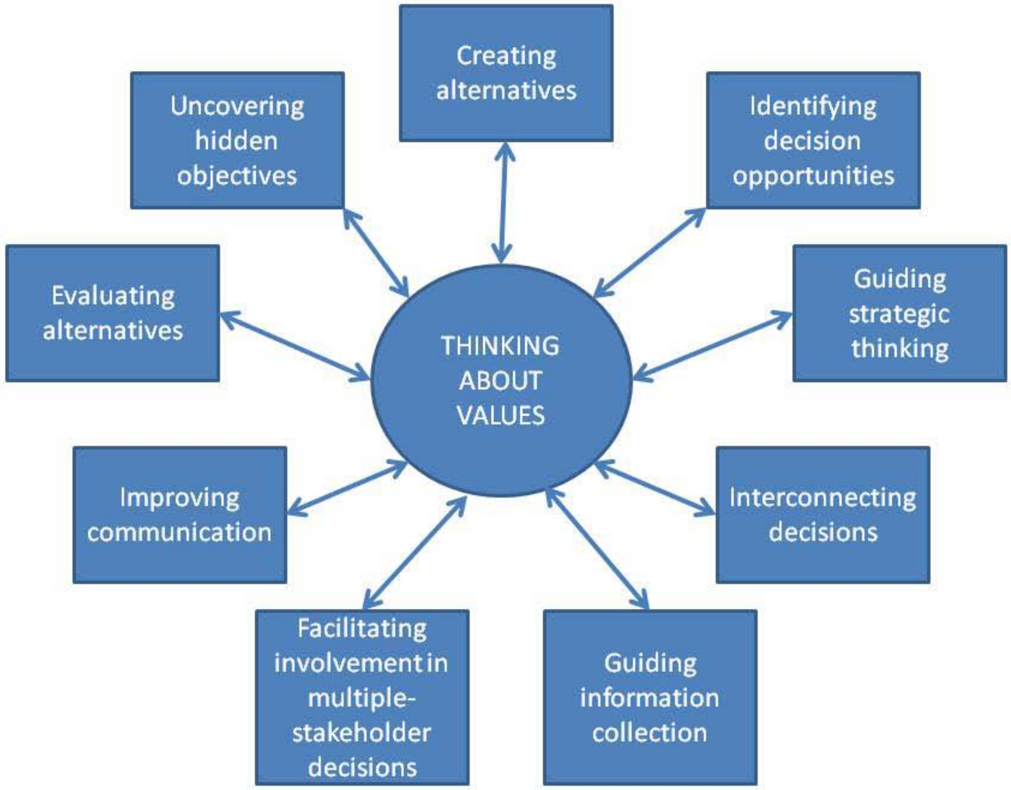


Figure 2 The Central Role of Thinking About Values (Keeney, 1992)

Shoviak (2001) derived a ten-step approach to proceed in the VFT process from the work of Keeney (1992) and Kirkwood (1997) who discuss the value focused thinking methodology for multi objective decision analysis problems, and Braziel (2004) illustrated these steps as shown in Figure 3. Note that these steps are iterative and not necessarily to be followed in an order.

In this research, we utilize the benefits of Value Focused Thinking in order to specify the values of the decision maker for a given multi objective decision problem, and then move it forward into a multi criteria decision making problem and find the optimality conditions for Turkish Air Force Flying Hour Program including the decision maker's values.

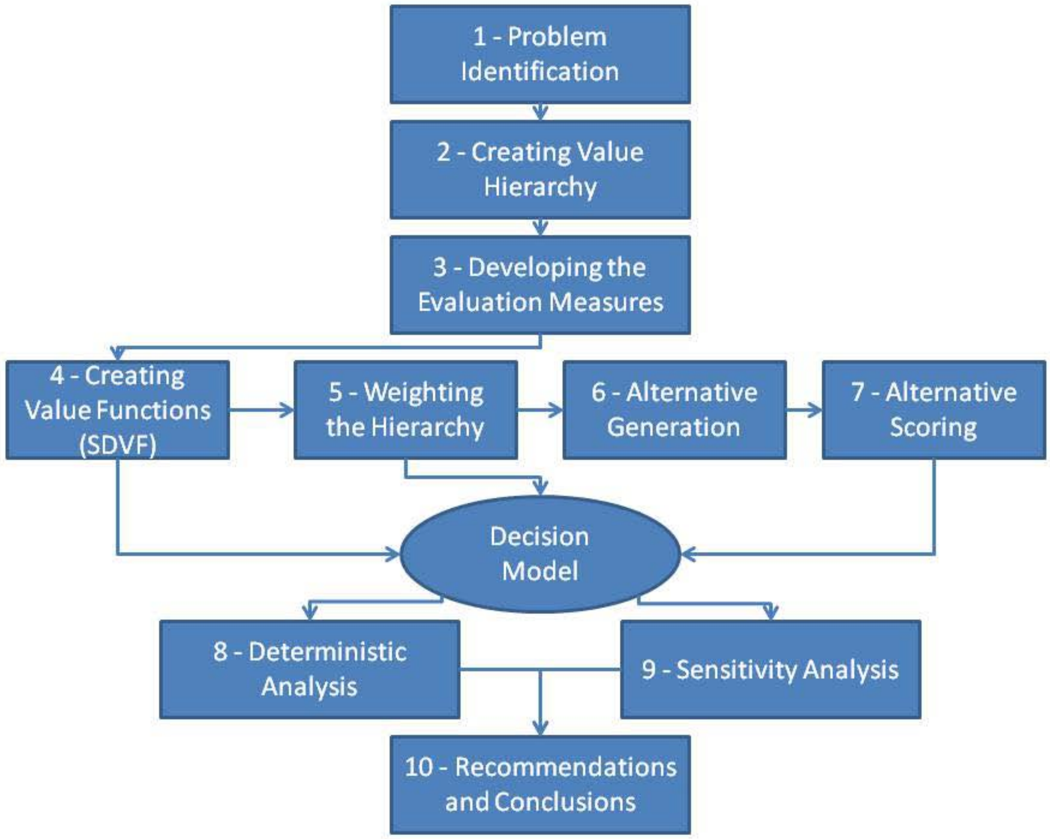


Figure 3 VFT Ten Step Process (Braziel, 2004)

2.2.1 Problem Identification

Problem Identification is the most important step in a decision situation. Keeney (1992) mentions the simplicity of listing objectives, however identifying, structuring, analyzing, and understanding objectives requires a deeper afford. Constructing your value model on an incorrectly defined decision situation will not only be useless, but also be a waste of time and resources.

2.2.2 Creating Value Hierarchy

Once the problem is identified and fundamental and sub objectives are elicited from the decision maker, we should organize the value hierarchy which is an illustration of the decision maker's objectives. Kirkwood (1997) defines a value hierarchy as a "treelike" structure, which consists of tiers; values the same distance from the top. A proper value structure will be hierarchical, including a Major Objective at the top, and Fundamental and their Sub Objectives, and then Attributes at the bottom which are measurable, as shown in Figure 4.

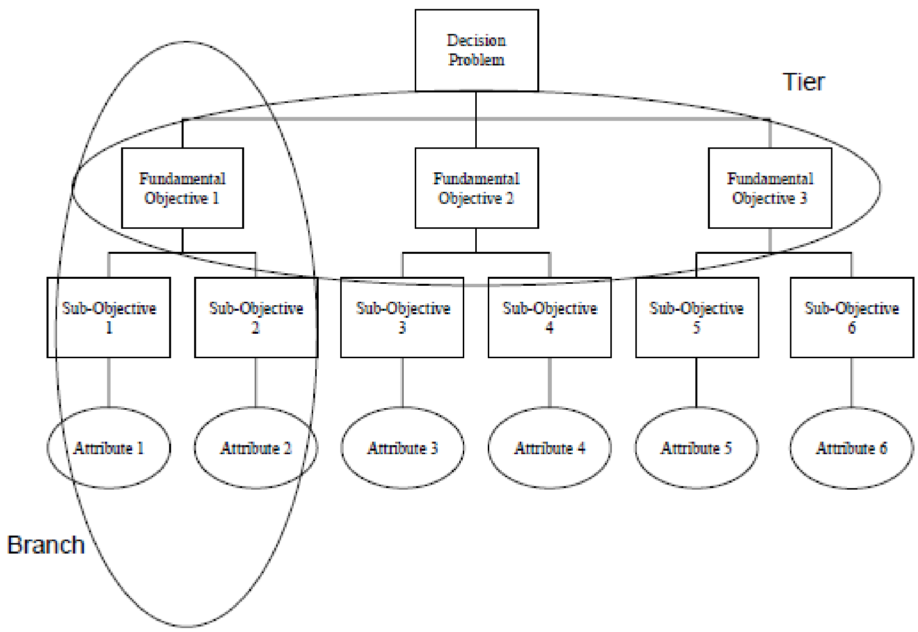


Figure 4 Example of a Generic Value Hierarchy (Fensterer, 2007)

There are some desired properties of value hierarchies, which are completeness, nonredundancy, decomposability, operability, and small size (Kirkwood, 1997). Completeness (collectively exhaustive) means a value model must reflect on all important types of evaluation, and nonredundancy (mutually exclusive) means there should not be any overlap between the tiers (Parnell, 2007). Decomposibility (independence) means none of the values of elements of the hierarchy should depend on the other, which means changing a value of an element should not cause a change in value of another. Operable means everyone involved in decision situation (DM, SMEs, Stakeholders, etc.) must interpret them in the same way. Finally, small size means we want the hierarchy to be as small as possible to provide simplicity for analyzing it (Kirkwood, 1997).

2.2.3 Developing the Evaluation Measures

In order to evaluate the alternatives, once the objectives are identified and structured, a measurement, called an Attribute, should exist for each objective. Kirkwood (1997) classifies attributes as natural or constructed, and either direct or proxy. A natural scale is one “that is in general use with a common interpretation by everyone” (Kirkwood, 1997). A constructed scale is one “that is developed for a particular decision problem to measure the degree of attainment of an objective” (Kirkwood, 1997). A direct scale “directly measures the degree of attainment of an objective, while a proxy scale reflects the degree of attainment of its associated objective, but does not directly measure this” (Kirkwood, 1997).

2.2.4 Creating Value Functions (SDVF)

In Value Focused Thinking, attributes are used to score alternatives. Single-dimensional value functions (SDVF) are used for a mathematical translation of each measure and provide a common scale. They convert different units in the value hierarchy into a single value unit between 0 and 1. SDVFs may be in the continuous forms as linear, piecewise linear or exponential (in the middle and RHS of the Figure 5) or in the discrete forms as categorical (LHS of the Figure 5), and they are either monotonically increasing or decreasing (Kirkwood, 1997).

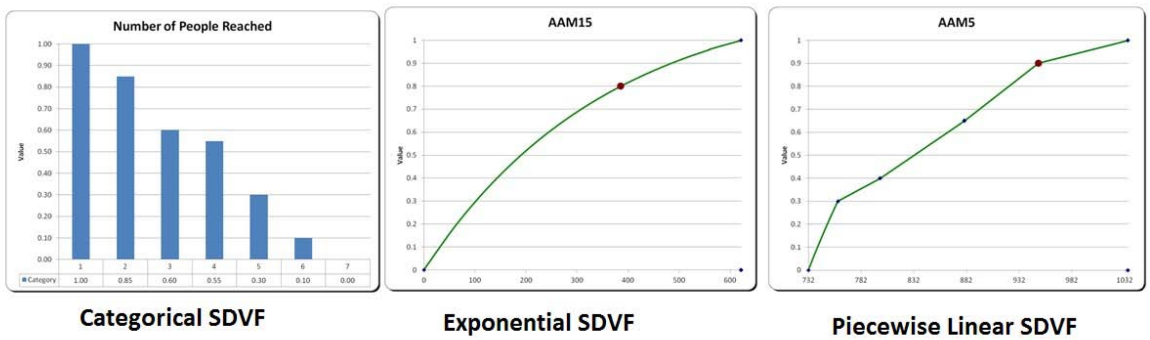


Figure 5 Examples of SDVFs (Dawley, Marenette, & Long, 2008)

2.2.5 Weighting the Hierarchy

After completing the single dimensional value functions, the decision maker should assign weights to the values in order to distinguish them according to their relative importance (Braziel, 2004). Weighting can be defined as local weights, which are the relative weights of the elements (fundamental objectives, sub-objectives, attributes) in the same tier of a branch in the value hierarchy, and global weights which are the weights of the lowest tier in the hierarchy (attributes). Global or local weights can be elicited from the decision maker considering the relative importance of the values. Either can also be calculated given the other. For example, global weights are calculated by the multiplication of the local weights of the relative values from top to bottom in the value hierarchy (Fensterer, 2007). The sum of the local weights within a tier of a branch must be equal to one; also the sum of global weights in the entire hierarchy must be equal to one.

There are several different methods in the literature in order to elicit the weights from the decision maker; Jia et al (1993) discuss some of them. According to Von Winterfeldt (1986) Swing Weight Method is one of the most preferred techniques among them because it captures the relative importance of the range of outcomes as well as the objectives themselves. In this method, we set all objectives or attributes at their worst levels and ask to the decision maker to move one of them to its best level. Then we ask the decision maker again to move another one to its best level among the rest of them and continue the process in the same manner until we finish all of them. The first preferred objective or attribute is assigned an arbitrary weight (let it be r1=100), and the others are assigned weights again in a decreasing manner (let them be r2=80, r3=50, r4=20) according to their relative importance. Completing this process gives us the rank ordered objectives or attributes and the relative importance weights for each one. At the end we normalize these weights using the following equation (Jia, Fischer, & S., 1993):

$$w_i = \frac{r_i}{\sum_{k=1,m} r_i}, \quad where\ 0 \leq w_i \leq 1\ and\ \sum_i w_i = 1 \qquad (1)$$

2.2.6 Alternative Generation

Up to this point, we elicit all the information that is needed to generate the alternatives according to the decision maker's values in the decision situation. We may think of the value hierarchy as an illustration of the frame for our decision situation. Now, we need to determine the alternatives that are eligible to be selected within this frame. In VFT, according to Keeney (1992) the principle is that alternatives should be created that best meet the values specified by the decision maker in the decision situation.

2.2.7 Alternative Scoring

Once the alternatives are generated, we need to convert all of them into a mathematical base that enables us to evaluate them quantitatively. We do this with the help of single dimensional value functions that enables us to make a mathematical translation as explained in step 4.

2.2.8 Deterministic Analysis

Once we have the single dimensional value functions (Step 4), the global weights of the attributes (Step 5), and the score for the alternatives (Step 7), we can use them to construct an overall value function in our decision model. This value function enables us to make a quantitative rank ordering between alternatives and gives insight to the decision maker (Shoviak, 2001).

In VFT, the most commonly used overall value function is the additive value function because it is simple to understand, to calculate, and enables the analysts make a broad sensitivity analysis on the results (Kirkwood, 1997). The following equation is used for additive value functions (Dawley, Marenette, & Long, 2008):

$$Value(X) = \sum_{i=1}^{n} w_i v_i\,(x_i), where\ 0 \leq w_i \leq 1\ and\ \sum_i w_i = 1 \qquad (2)$$

where,

$V(X)\ is\ the\ overall\ value\ of\ an\ alternative$

$w_i$is $the\ weight\ of\ the\ i^{th} measure$

$v_i(x_i)\ is\ the\ value\ of\ the\ score\ on\ the\ i^{th} measure$

$n\ is\ the\ total\ number\ of\ measures$

2.2.9 Sensitivity Analysis

After getting results from deterministic analysis, a sensitivity analysis should be applied to see if the preferred recommendation is sensitive to small changes in particular weights or assumptions in the model. If making small changes in particular weights or assumptions cause a big difference in our recommendation, the decision maker may want to reconsider that aspect of the model (Dillon-Merrill, S., L., R., & J., 2008).

2.2.10 Recommendations and Conclusions

This step is as important as the previous steps, because generally the decision maker(s) are more concerned about this part rather than the mathematical formulations, and calculations that are done by the analysts behind the scenes. Therefore, in this step we should exclude the confusing aspects of the model and prepare a clear and understandable presentation for the decision maker (Dillon-Merrill, S., L., R., & J., 2008).

Up to now, we have conducted a broad research in the literature for VFT and explained all the aspects that are commonly used in most of the research to give insight about VFT modeling. However, not all of these steps are being utilized in this research. This research utilizes the first 5 steps of VFT which are used to formulate the model representing the DM's values correctly, but from this step forward we are going to move the model into a goal programming formulation as a constraint. Generally, VFT is used to generate alternatives within the frame that the decision maker draws with his/her values as explained in the sixth step, and alternatives are evaluated based on their scores in the x-axis and their corresponding values in SDVFs. In this research we are seeking for an optimization formulation representing the DM's values, so we are using VFT this time backwards to find the values on the x-axis by implementing them in a goal programming formulation.

2.3 Goal Programming

Keeney (1992) mentions the similarities and differences of the terms in definition of goals, objectives, and constraints in his textbook. According to Keeney (1992) a goal refers to a specific level or a standard of a measure of an objective. An objective is different from a goal because it refers to more of a general aim in a decision situation therefore a better term used in VFT for creating and evaluating alternatives that makes the analysts, and DMs focus on the important aspects of the decision situation. He continues claiming that the constraints reversely correspond to goals where constraints limit the things that we can do, but goals sets a specific level for us to do (Keeney, 1992). Ragsdale (2004) contributes to this argument by differentiating them as hard constraints that cannot be violated and soft constraints or goals representing a target that the decision maker wants to achieve. In most of the real world decision situations, we might not have only one objective to be maximized or minimized over a set of constraints. Instead, we are more likely to have multiple goals that the decision maker wants to achieve which also allows for hard constraints. As an example, we may think about a decision situation for ourselves when we would like to buy a house at a minimum cost vs. buying the best house that may include the place (city), cost, size, safety, etc. factors in it. These kinds of decision problems are known as goal programming problems (Ragsdale, 2004). Lee (1972) defines Goal Programming as a technique that is capable of dealing with the decision situations with a single goal with multiple sub-goals, as well as the situations with multiple goals with multiple sub-goals.

Considering the assumptions and the notation of linear programming models, Schniederjans (1995) and Lee (1972) state that goal programming is an extension of linear programming. The general form of linear programming can be stated as the following equation (Lee, 1972):

$$Minimize: \quad Z = \mathrm{f(x)} = \sum_{j=1}^{n} c_j x_j$$

$$subject\ to: \quad \sum_{j=1}^{n} a_{ij} x_j \geq b_i, for\ i = 1,2, \dots, m \qquad (3)$$

$$x_j \geq 0, for\ j = 1,2, \dots, n$$

where,

x_j *is decision variables or unknowns*

c_j *is objective function coefficients*

a_{ij} *is technological coefficients*

In this kind of LP model, we may see the constraints in three types; less than or equal to, equal to, or greater than or equal. If one or more constraints are not satisfied then it means the solution is infeasible. Note that satisfying the constraints and finding a feasible solution set is prior to optimizing the objective function in a LP model (Schniederjans, 1995).

Charnes and Cooper (1977) consider these constraints individually as certain desired conditions which may be defined as goals. In this model we want to achieve these goals as closely as possible, therefore we may be penalized for the deviations from our desired goals. Charnes and Cooper (1977) call these conditions “goal functionals” obtained by subtracting the right hand side value (b_i) from both sides of the equality constraint (Schniederjans, 1995) which may be expressed as the following equation with the absolute value format:

$$f_i(x) = \left|\sum_{j=1}^{n} a_{ij}x_j - b_i\right|, for\ i = 1,2, \dots, m \quad (4)$$

Therefore, Charnes and Cooper (1977) present the general formulation of goal programming models with the equation below (Schniederjans, 1995):

$$Minimize: Z = \sum_{i \in m}^{n} (d_i^+ + d_i^-)$$

$$subject\ to: \sum_{j=1}^{n} a_{ij}x_j - d_i^+ + d_i^- = b_i,\ for\ i = 1,2, \dots, m \quad (5)$$

$$d_i^+, d_i^-, x_j \geq 0, for\ j = 1,2, \dots, n;\ for\ i = 1,2, \dots, m$$

where,

$d_i^+ is\ positive\ deviation\ variable$

$d_i^- is\ negative\ deviation\ variable$

$x_j\ is\ decision\ variables\ or\ unknowns$

$a_{ij}\ is\ technological\ coefficients$

Note that the objective function has no decision variables or objective function coefficients (c_j). This creates a unique difference between GP and the other quantitative methods (Schniederjans, 1995). In addition to this, the statement in the objective function that $i \in m$ implies we don’t have to include all deviation variables in it, the decision maker has the opportunity to choose from m possible deviation variables (positive or negative) (Schniederjans, 1995). Other than these, Charnes and Cooper (1977) state that we should always maintain $d_i^+ d_i^- = 0$, because of the fact that there can be only one direction for our deviation from our desired goal. We can not overachieve a goal while we have a shortage of the same goal at the same time.

Steuer (1986) defines two basic models in goal programming: the Archimedian model which may be inferred as weighted goal programming, and the preemptive model sometimes called the lexicographic goal programming.

In Archimedian (weighted) Goal Programming (Steuer, 1986), the decision maker is allowed to assign relative weights to the positive and the negative deviational variables which represent the importance of a deviational variable to be minimized among the others included in the objective function. A general model for weighted goal programming can be stated as the following (Schniederjans, 1995):

$$Minimize: Z = \sum_{i \in m}^{n} (w_i^+ d_i^+ + w_i^- d_i^-)$$

$$subject\ to: \sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = b_i, for\ i = 1,2,\dots,m \quad (6)$$

$$w_i^+, w_i^-, d_i^+, d_i^-, x_j \geq 0, for\ j = 1,2,\dots,n;\ for\ i = 1,2,\dots,m$$

In the weighted goal programming objective function, the values of the relative weights (w_i^+, w_i^-) can be any nonnegative constant (Charnes & Cooper, 1977). If the decision maker assigns a very large weight for a deviation variable, we may infer that this deviation from its respective goal is undesirable for our decision situation. Therefore, if the DM assigns a zero weight to a deviation variable it can be inferred that he/she is indifferent or neutral about that deviation or this deviation may be desirable for our decision situation (Ragsdale, 2004). This model looks to minimize the sum of the weighted deviations from all goals stated in the model (Schniederjans, 1995).

In Preemptive (Lexicographic) Goal Programming (Steuer, 1986), the decision maker has the opportunity to make a rank ordering of the goals in the model which is called an absolute priority structure by Charnes and Cooper (1977). In this structure, the deviation from the goal in the first priority is infinitely more important than the second one, which continues as second one is infinitely more important than the third, and so forth (Steuer, 1986). This implies that the model does not permit a substitution between the categories of goals and can be stated as (Schniederjans, 1995):

$$Minimize: Z = \sum_{i \in m}^{n} P_i \, (d_i^+ + d_i^-)$$

$$subject\ to: \sum_{j=1}^{n} a_{ij}x_j - d_i^+ + d_i^- = b_i,\ for\ i = 1,2,\dots,m \qquad (7)$$

$$d_i^+, d_i^-, x_j \geq 0, for\ j = 1,2,\dots,n;\ for\ i = 1,2,\dots,m$$

However we may find several types of GP variants in the literature as Schniederjans (1995), Steuer (1986), Jones and Tamiz (2010), Ignizio and Romero (2011) suggest in their textbooks and articles. We may observe that all GP modelings are derived from these two types; weighted goal programming and lexicographic goal programming (Schniederjans, 1995).

In the objective function, we see both negative and the positive deviation variables are included in the general formulation; however, the decision maker can decide which deviation variable should be included in the objective function according to the analysis of the decision problem. For instance, if overachievement is satisfactory for a goal, then the positive deviation of that goal can be excluded from the objective function, hence we can conclude that the negative deviation variable can be excluded when underachievement of that goal is acceptable (Lee, 1972).

2.4 Research Contribution

The first contribution of this research is that one of the assumptions of goal programming that all goal constraints are in linear relationships, so that the problem can be solved by goal programming (Lee, 1972). We may see this linear relationship in the equation 4, which is defined as a goal functional by Charnes and Cooper (1977). However, there may be some cases where we have to define an interval for our decision variables with minimum and maximum levels in which case the decision maker may not value each number within that interval the same. This creates a nonlinear function. We may formulate this kind of a problem by setting our goal to the maximum level with only defining a negative deviation variable in the goal functional. Then we may simply define a hard constraint for the negative deviation variable ensuring that it does not go below the difference between the maximum and the minimum level of that decision variable, therefore the objective function becomes a minimization for negative deviation variables. Nevertheless, in this case we have to ignore the fact that the decision maker does not give the same value for every number between those intervals. In addition, the mathematical formulation can be very complicated when we have several decision variables. And, with several deviation variables it makes it very hard to interact with the decision maker. Therefore, we suggest that with our methodology VFT can be used in this kind of decision situations by utilizing the benefits of single dimensional value functions. We may see a similar study in Ringuest (1992)'s textbook, using single attribute value functions in goal programming objective function by approximating them with piecewise linear functions. Our methodology is different from this study. First we are using them as a constraint and leave the original goal programming objective function including only the deviation variables which creates the difference between GP and other methods as stated in Schniederjans (1995)'s textbook. Secondly, we make use of an exponential single dimensional value function instead of trying to approximate them by piecewise linear functions. From our point of view, SDVFs are eligible to be used in this sense because they are convex. This approach also allows us to include all decision variables with the same type in one goal functional.. That is, using the additive value functions shown in equation 2,the mathematical formulation can be expressed in only one goal functional including all decision variables in it.

The second contribution of this research is about scaling in goal programming. Schniederjans (1995) makes a broad discussion about incommensurability issues in goal programming formulations in his text book by mentioning that goals in GP formulations generally correspond to very different types, i.e budget goal measured in dollars vs quality of water measured with pH level. When we think about some other examples like this in a weighted goal programming formulation, we expect the DM to compare apples and oranges together (Schniederjans, 1995). This issue may even occur with the same types of goals in a goal programming model. We may have some problems about scaling (commensurability) in our decision situation when we have so many decision variables with different scales regarding the same type of goal. For instance, we may think about

Turkish Air Force Flying Hour Program which has so many different mission types with different number of required flying hours with their minimums and maximums. If you think about two of them, let one of them be M1 (mission 1) with number of required flying hours at a minimum of 3000 and a maximum of 4000, and the other one M2 (mission 2) at a minimum 300 and a maximum 400; if the decision maker were to select one or the other when a need of reduction occurs for 1 flying hour, it is hard make a judgment about selecting 3999 vs 399 flying hours. Now, think about making the same judgment between 200 missions or maybe more. For this reason, in these cases VFT may be useful to scale all decision variables between 0 and 1 by using single dimensional value functions. It facilitates a better understanding of the trade-offs between decision variables for the decision maker and the methodology we propose may overcome the issues stated by Schniederjans (1995) about incommensurability.

The final contribution of this research is about weighting. Schniederjans (1995) also discusses some issues that can happen about weighting in goal programming formulations in his text book, and he suggests that the analysts can overcome these issues by stressing more on their calculations. Many researchers such as Knoll and Engelberg (1978) and Cook and Kress (1988) suggest different techniques for weighting in goal programming. In goal programming we may use any weighting technique as in VFT which are explained in section 2.2.5 (Weigting the Hierarchy) or the DM may use any nonnegative constant in order to give relative weights to the deviation variables. But, when there exists so many deviation variables in the decision situation, it may be very complicated to weight this many variables just by looking at the mathematical formulation of a goal programming model which does not make sense to most of the decision maker(s). As stated in section 2.2.10 (Recommendations and Conclusions) the decision maker(s) is more concerned about the results rather than the mathematical background behind them. Hence, the visualization of VFT may help the DM while weighting these values. The value hiearachy reflects the values of the decision maker as stated in section 2.2.2 (Creating the Value Hierarchy), thus it becomes easier for the decision maker to weight a visual tool created according to his/her own values. With this aspect of our methodology, we suggest an easier way of dealing with the weighting concerns discussed by many of the researchers such as Schenkerman (1991), Sherali and Soyster (1983), and Schniederjans (1995) in their articles and books while formulating goal programming models.

Up to now, value focused thinking and goal programming are detailed by conducting a literature review. Then, the contribution of this research to the literature is explained with its three important aspects. In the following chapter, we propose our methodology and then illustrate its application with a real world problem, Turkish Air Force Flying Hour Program.

III. Methodology

In this chapter, we first introduce the background of the case study, Turkish Air Force Flying Hour Program, and then explain the objectives and assumptions that are made specifically for this problem in order to implement our methodology. Rather than mathematically expressing our methodology first, then illustrating it in the case study we progress both at the same time, hence the readers may understand it better and easier. The solution to the problem includes VFT and goal programming. First, it builds the value hierarchy, then determines the evaluation measures and the functions, and weights the hierarchy by using the swing weight method. Subsequently, it takes this model and uses it as a constraint in a goal programming formulation by setting a goal for the combat readiness level and also has a budget goal. Finally, the verification of the model is discussed.

3.1 A Case Study: Turkish Air Force Flying Hour Program

3.1.1 Background:

By being a partner of F-35 Joint Strike Fighter Program, many considerations occurred in a variety of fields for the Turkish Air Force, because of the fact that the upcoming next generation strike aircraft requires different applications than the Turkish Air Force is currently implementing. One of the areas that brings a revision requirement for The Turkish Air Force Flying Hour Program due to the upcoming next generation strike aircraft, F-35 Joint Strike Fighter, is performance based logistics and performance based agreements which are introduced in chapter 1. . The current program is being prepared according to the official documents (doctrines, guidelines, etc.) and the budget constraint and is not seeking optimality.

The TurAF has a variety of aircraft (e.g. cargo, fighter, training, etc.) in its inventory. Although all of these may need to be examined according to the changes of requirements in aviation with the developing technologies, this case study focuses only on the fighter aircraft because of the fact that F-35 Joint Strike Fighter Program brought the overall idea of this research. So, the main point of interest is to establish an effective decision support model for the TurAF headquarters to prepare the flying hour program reflecting the decision maker’s preferences and considering the budget constraints which are going to be more important in the future while making the PBAs with the contractors. Once you obtain the base model, this model may be modified at anytime by making only small changes for different aircraft as well as the other decision support models in the literature on any subject.

From this point forward, the terms flight requirements and flying hour program are used with respect to the fighter aircraft that the TurAF has in its inventory. There are a variety of flight tasks that a flight squadron should fly in order to maintain its combat readiness level for a variety of missions. Therefore, when you think about different aircraft and squadrons with different missions (e.g. air to air, air to ground, etc.) with a changing number of pilots each year, assigning tasks to the squadrons considering their current and predicted requirements within each fiscal year is a really complicated problem for the related TurAF officials. Another important constraint about this problem is budget, which may change for every fiscal year as well and makes the problem more complicated. Currently, the method used by the TurAF for preparing a Flying Hour Program is being implemented according to the official documents (doctrines, guidelines, etc.) and the budget constraint doesn't seem to be binding because the maintenance of the aircraft are being done within the Air Force and there are no such agreements with outside contractors for this purpose. So, the budget is spent within the Air Force which can be changed according to the needs of the TurAF from one expenditure item to another. Therefore, the current method is not really trying to find the optimum values of flying hours. On the other hand, with the implementation of PBL and PBAs, it is going to be a big concern because there will be outside contractors and the expenditure on the agreement will be a binding constraint for TurAF. Otherwise making these evaluations and calculations wrong or specifying the need incorrectly on the agreements may result in a shortage in completing the required flight tasks or paying out more than required. The TurAF seeks to find the optimum flight hours and the related analysis in order to achieve successful PBAs. However, this is the final intention for the implementation of PBL in TurAF; it requires a broad research considering every aspect and their consequences that can be accomplished in a few steps.

Consequently, this case study is seeking a model to redefine the flight requirements and optimizing the Air Force Flying Hour Program.

3.1.2 Case Study Objectives and Assumptions

The multi criteria optimization problem of Turkish Air Force Flying Hour Program gives the motivation of this case study. Preparing the flying hour program for Turkish Air Force yearly by hand is an exhausting process and highly open to making errors. If the process was handled with an optimization technique such as a multi criteria optimization, it could be done easier and reduce the probability of making errors as well as the working hours and can also prevent TurAF from flying more than needed while providing the required portion to be combat ready. Hence, the main objective is to create a decision support model to find the optimal number for flying hour program while taking into account the budget constraint and the decision maker's values, which are extremely important for TurAF in order to achieve successful PBAs.

In the TurAF Headquarters, a department under the Operation Directorate manages this procedure. Neither the bases nor the squadrons are involved in the process. Thus, the Flight Education Branch is dealing with all the workload of this challenging process. However, this model will only take the fighter aircraft into account, the Flight Education Branch also deals with all other aircraft in the inventory. Subsequently, the second objective of this case study is to build a model which is expandable to capture all of the elements under the responsibility of the Flight Education Branch in the TurAF Headquarters.

As explained above, currently the officials prepare the Flying Hour Program manually regarding to the documents. But, when we consider all of the squadrons with different types of tasks and with changing number of pilots with different categories every year, doing this job is time consuming and may result in lots of errors which can create a pressure in the base and the squadron level. Therefore, as the third objective of this case study, we are seeking a model which provides a time saving process enabling the officials to predict the possible errors and take necessary measures in advance.

This case study makes the following assumptions regarding the decision problem stated above:

- Only F-4 and F-16 aircraft types are included in the model, other aircraft types are excluded from the scope of this research.
- All F-4 and F-16 aircraft in the inventory are considered to be available for flying all the time. Therefore, the availability of the aircraft is excluded from the scope of this research.
- All F-4 and F-16 aircraft are eligible to fly the same mission types.
- Other flight tasks and mission types that are not common to fly in a regular fiscal year are excluded from the scope of this research.
- The cost of a flying hour for the aircraft (F-4, F-16) is taken to be the same for each mission belonging to those aircraft type independent from the required altitude for that mission, as well as the required maintenance schedule to be followed.
- Currently there is no such binding budget constraint for the Air Force to expend on flying hours; therefore, random budget data is used.
- Any category pilot (A,B,C,D) should fly the minimum required flying hours determined by the headquarters in order to be combat ready, and cannot exceed the maximum.
- One sortie of a mission is taken as an average to be 1.1-hours of flying.

The first step of this optimization process, uses Value Focused Thinking to define the flight requirements and elicit the Decision Maker's values and preferences in terms of main air tasks, squadrons, aircraft and missions in Turkish Air Force. The value Hierarchy is created according to the TurAF flight requirements with the help of subject matter of experts (SME). Secondly, this model is implemented into a goal programming model as a constraint which has some goals in the formulation with regard to the budget limitation and the decision maker's goal representing the point he/she wants to see Turkish Air Force be at in terms of combat readiness at the end of the year. Hence, this research develops a flexible, time saving, easy to understand and structured model for TurAF headquarters to use in order to prepare the TurAF Flying Hour Program.

3.2 Model Formulation

For this part, we use the first five steps of value focused thinking as stated in chapter 2. Then we move it forward into our goal programming formulation. For the five steps of value focused thinking approach, we completed the first step, problem identification, in the beginning of this chapter. Thus, the objective of preparing an optimized flying hour program is to maximize the Turkish Air Force's combat readiness level.

3.2.1 Creating Value Hierarchy

As stated in chapter 2, we construct the value hierarchy according to the decision maker's values about the decision problem. In this case, we create the value hierarchy according to the opinions of the subject matter of experts (SME) in the Operation Directorate. After writing the decision problem into the top box, we then place the values elicited from the SMEs under the top box as the first tier of the hierarchy. These are the flight tasks that the Air Force flies that separate into four main groups as air to air, air to ground, night and others (some special courses, standardization tasks, etc). In a given year, the decision maker has the opportunity to give more importance to one or two of the tasks than the others, i.e the decision maker may wish to give more importance to air to air tasks, rather than the others due to the developments in aviation. Thus, these four tasks form the first tier of the value hierarchy shown in Figure 6. We use Hierarchy Builder Software Version 2.0 (Weir, 2008) in order to create our model.

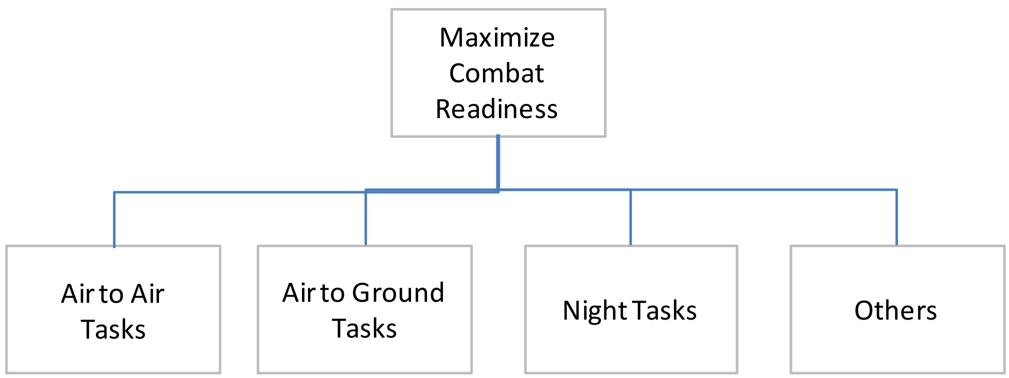


Figure 6 Overall Objective and the First Tier of the Value Hierarchy

These values are followed by the sub-values as represented in the second tier and the third tier of the hierarchy shown in Figure 7. In the second tier, we see the fighter squadrons separated according to their functions as air to air squadrons and air to ground squadrons. In Figure 7, only the first branch of the hierarchy is illustrated because of the fact that all other flight tasks are constructed in the same manner. All of the flight tasks, regardless of the type, can be flown by either an air to air squadron or an air to ground squadron. It is obvious that air to air tasks should be flown by air to air squadrons as well as the air to ground tasks should be flown by air to ground squadrons. On the other hand, in some cases the decision maker may wish to adjust the intensity by expressing his/her preferences. (e.g. he/she may want 70% of the air to air tasks to be flown by air to air squadrons and 30% of them to be flown by air to ground squadrons which may be subject to change in the following years.) In addition, the night tasks and the other tasks still need to be determined by the decision maker. Hence, air to air squadrons and the air to ground squadrons form the second tier of the value hierarchy. The Turkish Air Force has only F-16 aircraft in its air to air squadrons, however it has F-4 and F-16 aircraft in its air to ground squadrons (Sevel, 2007). Although, F-4 and F-16 aircraft are different in mission capabilities, they can still fly the same missions (Sevel, 2007). The decision maker can determine which aircraft to fly more in a given year, thus these two different aircraft take place in the third tier in the value hierarchy. As a similar example, the decision maker may want 60% of the air to air tasks that are assigned to air to ground squadrons to be flown by F-16 aircraft and 40% of them to be flown by F-4 aircraft which is changeable in the following years.

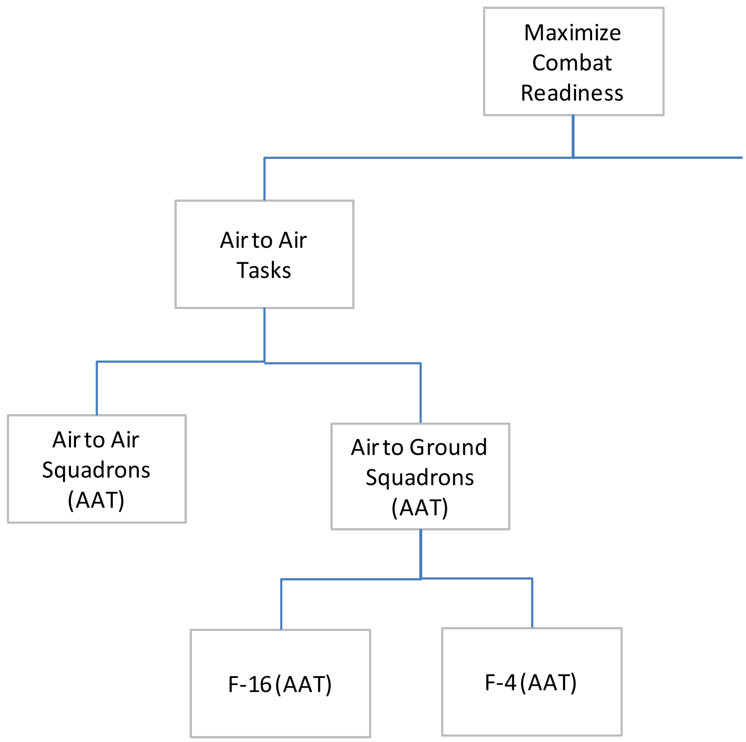


Figure 7 Second and the Third Tier of the Value Hierarchy

3.2.2 Developing the Evaluation Measures

Another step of building the value hierarchy is to develop the evaluation measures. There are 45 evaluation measures in total constructed for our decision situation. However, Durkan (2011) states that a fighter squadron has roughly 50 missions in his thesis research, this case is in more at the operational level. The planners in the headquarters are only concerned with the main mission types which are thought of at the strategic level not the detailed mission types that are distributed within the squadrons. An example of evaluation measures is illustrated in Figure 8. As we see from the figure there are five types of air to air tasks for this research which are also assumed to be valid for the air to ground squadrons (F-4 and F-16 aircraft). Therefore, we have five air to air missions, six air to ground missions, two night missions, and two other missions which are all assumed to be the same numbers for air to air and air to ground squadrons as well as the F-4 and F-16 aircraft. Thus, we have 45 evaluation measures. Instead of using the real names for the mission types, they are represented as Mission-1, Mission-2,…,Mission-n changing according to the types as air to air mission (AAM), air to ground mission(AGM), night mission (N), and other mission (O).

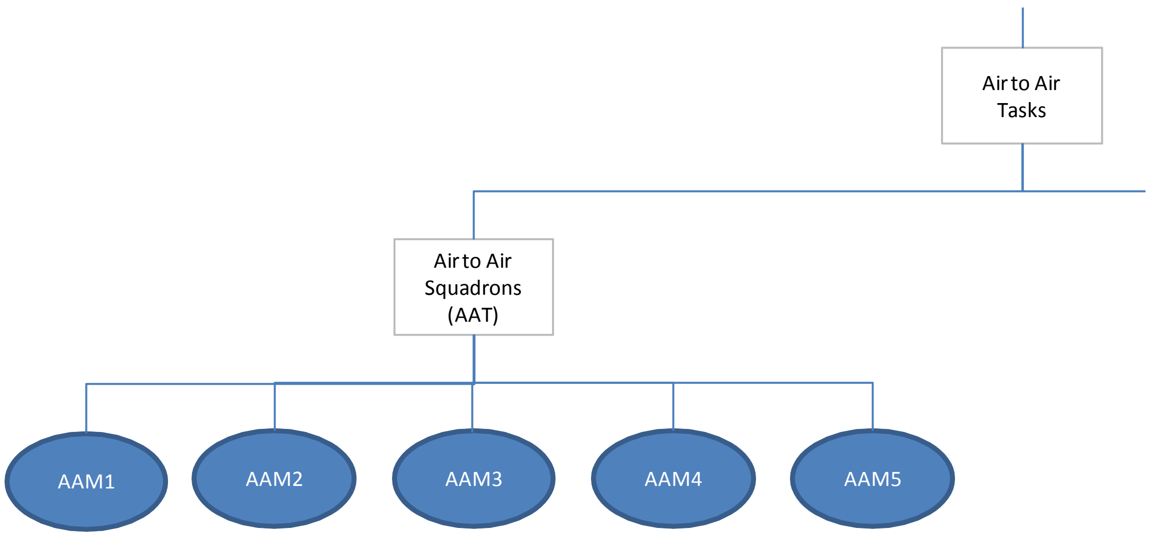


Figure 8 Air to Air Squadrons Evaluation Measures for Air to Air Flight Tasks

3.2.3 Creating Value Functions (SDVF)

Once we create the value hierarchy according to the values of the decision maker, we can progress in developing the value functions. We may make use of all value functions in VFT that are illustrated in chapter 2, but in our decision situation only exponential single dimensional value functions are used according to the elicitation we make from the SMEs. SDVFs are one of the key points of this research as explained in chapter 2.

In the Turkish Air Force, there is a minimum requirement for a pilot to be combat ready from a specific mission measured in sorties; hence, a pilot should fly that minimum number of sorties for that mission in a given year to keep his/her combat ready status. These minimum numbers are written in the official documents of Turkish Air Force for each category (A, B, C, and D) of pilots. On the other hand, there is maximum number of sorties for each mission that the Turkish Air Force does not want the pilots to fly for each category (A, B, C, and D). In addition, the value of each sortie that a pilot flies is not the same as another. If we think of an inexperienced pilot in a squadron, it is important for him/her to fly the minimum required sorties which are enough to be combat ready for him/her. Nevertheless, it is better for him/her to fly more to gain experience on that mission, hence he/she would progress in his/her flight career and the Turkish Air Force would have more experienced pilots. Although we may think that the more sorties he/she flies the more experience he/she gains, this situation is valid up to some point. In addition to the minimum requirement, the first sorties may be significantly beneficial for the pilots, but there is some point for that mission for which flying more does not give the benefit as much as the first ones and there is a peak where the additional sortie doesn't mean anything other than an extra sortie after that. This situation is illustrated in Figure 9 as an example. Note that in our decision situation, the officials are dealing with all fighter aircraft pilots separated according to the squadron (air to air, air to ground) and aircraft types (F-4, F-16). Hence, this figure represents the minimum requirement and maximum number of flying hours for all pilots with different categories (A, B, C, and D) not for an individual pilot for this specific mission. Using Table 2 obtains these numbers;

Table 2 Calculation of Example Mission for Minimum and Maximum Hours of Flying

Example Mission			
Pilot Categories	Minimum (hours)	Maximum (hours)	Number of Pilots
A	7	10	200
B	5	8	300
C	2	4	120
D	1	2	100
Total	3240	5080	

In this table, the first column shows the mission name and number, and the pilot categories. Second column is the minimum required flying hours for each category of pilots, the third column is the maximum number of flying hours for each category of pilot that the Air Force does not want to exceed, and on the right column, we have the number of pilots for each category. In order to obtain the total minimum number, we simply multiply the corresponding rows of the second and the forth column then sum up these multiplications. For the maximum number we also do the same calculation. Note that we converted sorties into hours by taking average sortie duration as 1.1 hours for this research.

After obtaining our data for the minimums and maximums, we create the SDVFs as in Figure 9 by using Hierarchy Builder Software Version 2.0 (Weir, 2008). According to this value function, the minimum number of flying hours has the value of zero since all pilots should fly this number, and the maximum of flying hours has the value of one since we do not want the overall flying hours to exceed this number. The break points are obtained according to the inputs of SMEs, hence we have all our SDVFs exponentially increasing and convex.

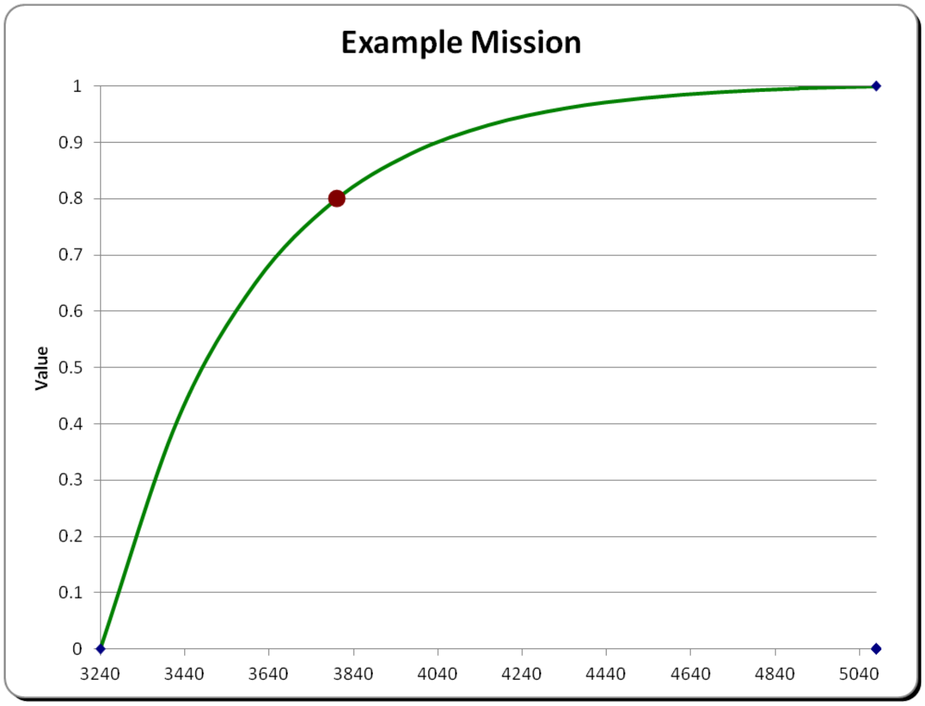


Figure 9 SDVF for Example Mission

In normal cases, VFT is used to create alternatives and it assesses the alternatives by scoring them using SDVFs. Therefore, the alternatives are converted from qualitative choices to quantitative ones that are eligible to be analyzed mathematically. However, in our case, we use SDVFs to find the optimum values first (between 0 and 1), and then their corresponding x-axis values which are flying hours in our case. According to Kirkwood (1997), when preferences are monotonically increasing over an evaluation measure x, which in our case meaning that higher amounts of flying hour are preferred to lower amounts as in Figure 9, exponential SDVFs can use the following equation which we use in our goal programming model (Kirkwood, 1997).

$$v_i(x_i) = \begin{cases} \dfrac{1-e^{\left[-\frac{x-x_{min}}{\rho}\right]}}{1-e^{\left[-\frac{x_{max}-x_{min}}{\rho}\right]}} & ,\rho \neq infinity \\ \dfrac{x-x_{min}}{x_{max}-x_{min}} & ,otherwise \end{cases} \tag{8}$$

where,

ρ *is exponential constant*

x_{min} *is the lowest value for* x

x_{max} *is the highest value for* x

3.2.4 Weighting the Hierarchy

As stated in chapter 2, weighting is one of the key contributions of this research regarding to issues stated by Schniederjans (1995). The Swing weighting technique is used to assess the values in the hierarchy as explained in chapter 2. First, we begin eliciting the weights from the top tier of the value hierarchy, and then we move to the second and the third tier weighting within each branch. After completly eliciting the local weights by swing weighting technique, we then calculate the global weights by using Hierarchy Builder Software Version 2.0 (Weir, 2008). Finally, we check the global weights with the SMEs again in order to verify that they reflect their true preferences; hence, the consistency check is completed. The global weights are shown in Table 3.

Table 3 Global Weights

AAT / AAS / AAM1	0.065	AGT / AAS / AGM1	0.013	NT / AAS / N1	0.056	OT / AAS / O1	0.043
AAT / AAS / AAM2	0.044	AGT / AAS / AGM2	0.009	NT / AAS / N2	0.045	OT / AAS / O2	0.048
AAT / AAS / AAM3	0.068	AGT / AAS / AGM3	0.003	NT / AGS / F-16 / N1	0.028	OT / AGS / F-16 / O1	0.025
AAT / AAS / AAM4	0.055	AGT / AAS / AGM4	0.01	NT / AGS / F-16 / N2	0.034	OT / AGS / F-16 / O2	0.021
AAT / AAS / AAM5	0.02	AGT / AAS / AGM5	0.009	NT / AGS / F-4 / N1	0.027	OT / AGS / F-4 / O1	0.024
AAT / AGS / F-16 / AAM1	0.007	AGT / AAS / AGM6	0.006	NT / AGS / F-4 / N2	0.023	OT / AGS / F-4 / O2	0.022
AAT / AGS / F-16 / AAM2	0.006	AGT / AGS / F-16 / AGM1	0.018				
AAT / AGS / F-16 / AAM3	0.005	AGT / AGS / F-16 / AGM2	0.03	* AAT: Air to Air Tasks			
AAT / AGS / F-16 / AAM4	0.006	AGT / AGS / F-16 / AGM3	0.028	*AGT: Air to Ground Tasks			
AAT / AGS / F-16 / AAM5	0.001	AGT / AGS / F-16 / AGM4	0.024	*NT: Night Tasks			
AAT / AGS / F-4 / AAM1	0.006	AGT / AGS / F-16 / AGM5	0.006	*OT: Other Tasks			
AAT / AGS / F-4 / AAM2	0.007	AGT / AGS / F-16 / AGM6	0.021	*AAS: Air to Air Squadrons			
AAT / AGS / F-4 / AAM3	0.002	AGT / AGS / F-4 / AGM1	0.021	*AGS: Air to Gorund Squadrons			
AAT / AGS / F-4 / AAM4	0.004	AGT / AGS / F-4 / AGM2	0.019	*AAM: Air to Air Mission			
AAT / AGS / F-4 / AAM5	0.007	AGT / AGS / F-4 / AGM3	0.027	*AGM: Air to Ground Mission			
		AGT / AGS / F-4 / AGM4	0.03	*N: Night Mission			
		AGT / AGS / F-4 / AGM5	0.024	*O: Other Mission			
		AGT / AGS / F-4 / AGM6	0.006				

After completing the weighting of the hierarchy, we have finished the first phase of our methodology related to value focused thinking. Now, we can move the data we obtain from this phase to a goal programming formulation to find the optimal flying hour program for the Turkish Air Force. In the following part, we set up our goal programming model and use our VFT model as a constraint in this formulation.

3.2.5 Goal Programming

Recall from chapter 2, there are two types for goal programming, weighted goal programming and lexicographic goal programming (Schniederjans, 1995). Ignizio (1980) makes a broad comparison of some methods used in goal programming in his research and concludes that, lexicographic goal programming is more suitable for real world problems in terms of modeling efficiency, robustness, computational performance, interaction with the decision maker, and results obtained in practice. In most of the real world decision situations, the decision makers tend to be more comfortable about rank ordering the goals instead of weighting them (Weir, 2011).

However, in our case, lexicographic goal programming is not adequate to give insight to the decision maker about the results. Solving lexicographic goal programming gives us only one result, because it solves the problem sequentially according to the prioritization. In our case, all of the flying hours belonging to each mission are our decision variables related to the available budget. Therefore, if we use lexicographic goal programming, the program would start solving by achieving 100% of the flying hours for each mission according to their prioritized order until it reaches the maximum available budget. In which case, we may not need to solve the problem using a tool like Excel

Solver 2007 or a formulation. If the decision maker could make this kind of a prioritization, then we can fly the maximum flying hours in this order for some number of missions and it means all other missions will be at their minimums. Notice that this situation is specific for our problem, for other decision problems, we could still use lexicographic goal programming. Nevertheless, for Turkish Air Force Flying Hour Program we use weighted goal programming to obtain more insightful analysis which is explained in chapter 4 rather than only one optimal solution to the problem.

First, we build our formulation as a lexicographic goal programming model to illustrate that how we can formulate the problem in this sense. Then we convert it to weighted goal programming to solve our problem. We start with formulating our constraints;

We have equation 8 for exponential SDVFs as,

$$v_i(x_i) = \frac{1-e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1-e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} \quad , \rho \neq infinity \tag{8}$$

As we state in chapter 2, the decision maker may wish to define a goal for Turkish Air Force, to represent the point that he/she would like to see it at the end of the given year. Hence, we can formulate this as the following constraint for the value that the decision maker sets for the Turkish Air Force, and generalize it for all measures we have,

$$v_i(x_i) + \ d_i^- - \ d_i^+ = g_i, where\ i = 1,2, \dots ,45 \tag{9}$$

where,

$v_i(x_i)$ is $the\ value\ of\ the\ score\ on\ the\ i^{th} measure$

d_i^+ $is\ positive\ deviation\ variable$

d_{i}^{-} $is\ negative\ deviation\ variable$

$g_i\ is\ the\ goal\ we\ want\ to\ achieve\ for\ the\ i^{th} measure, where\ g_i \epsilon$ [0,1]

If we replace $v_i(x_i)$ in equation 9 with equation 8, then we have the first constraint as the following,

$$\frac{1-e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1-e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} + d_i^- - d_i^+ = g_i\ , where\ i = 1,2, \ldots ,45 \qquad (10)$$

In addition to this first constraint, we have to define some hard constraints as well to ensure that x_i stays within the upper limits and the lower limits for each measure, hence,

$$x_{i_{min}} \leq x_i \leq x_{i_{max}}\ , where\ i = 1,2, \ldots ,45 \qquad (11)$$

For the next constraint, we formulate the budget limitation for our decision situation, so we have the following equation,

$$\sum c_i x_i + d_B^- - d_B^+ = g_B \qquad (12)$$

where,

c_{i} $is\ cost\ per\ flying\ hour\ for\ mission\ i$

x_{i} is decision variable

d_{B}^{+} is $positive\ deviation\ variable$

d_{B}^{-} is $negative\ deviation\ variable$

$g_B\ is\ budget\ goal\ we\ want\ to\ achieve$

To conclude, if we want to write our objective function for goal programming we may write some equations in order to obtain our final objective function. Recall from chapter 3.3.3 (Creating Value Functions (SDVF)), according to the value function, the minimum number of flying hours has the value of zero since all pilots should fly this number, and the maximum of flying hours has the value of one since we do not want the overall flying hours to exceed this number. Besides, we want to fly this maximum number. Hence, we can write the following equation for value function,

If we define our goal as 1 which cannot be overachieved,

$$v_i(x_i) + d_i^- = 1 \quad (13)$$

If we leave value function alone in this equation, we obtain,

$$v_i(x_i) = 1 - d_i^- \quad (14)$$

In VFT we want to maximize our objective function as,

$$\max \sum_{i=1}^{n} w_i v_i\,(x_i) \quad (15)$$

Therefore,

$$\max \sum_{i=1}^{n} w_i (1 - d_i^-) \quad (16)$$

If we reverse this function to a minimization problem for goal programming by multiplying it with -1 then we have,

$$\min - \left(\sum_{i=1}^{n} w_i (1 - d_i^-)\right) \quad (17)$$

Since, we know that $\sum_i w_i = 1$, we can write,

$$\min \sum_{i=1}^{n} w_i\, \mathrm{d}_\mathrm{i}^- \quad (18)$$

Hence, the objective function becomes including the budget constraint,

$$\min \sum_{i=1}^{45} \mathrm{P}_1 (w_i\, \mathrm{d}_\mathrm{i}^-) + P_2 \mathrm{d}_\mathrm{B}^+ \quad (19)$$

$where\ P_i (i = 1{,}2)$ represents the lexicographic order of the objectives respectively.

Note that, we can also use the original formulation of the value function in equation 2 and then replace $v_i(x_i)$ in equation 2 with equation 8, in which case we would have one equation and one deviation variable belonging to that equation as the first constraint. When we solve the objective function for that constraint, however, it could be computationally feasible we may have some x values zero in order to satisfy our goal, which is not desired for our case. Nevertheless, it is useful to keep in mind that some cases may be suitable for this formulation.

So, if we write our model formulation for Turkish Air Force Flying Hour Program, the objective function becomes; The Turkish Air Force first wants to minimize the negative deviation from the goal related to maximizing combat readiness level, while minimizing the positive deviation from the budget goal defined at the beginning of the year,

$$\min \mathrm{Z} = \sum_{i=1}^{45} \mathrm{P}_1 (w_i \, \mathrm{d}_\mathrm{i}^-) + P_2 \mathrm{d}_\mathrm{B}^+$$

Subject to:

$$\frac{1 - e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1 - e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} + d_i^- - d_i^+ = g_i \text{ , } i = 1,2, \dots ,45$$

$$x_{i_{min}} \leq x_i \leq x_{i_{max}} \text{ , } where\ i = 1,2, \dots ,45$$

$$\sum c_i x_i + d_B^- - d_B^+ = g_B$$

$$x_i, w_i, d_i^-, d_i^+, d_B^-, d_B^+, P_1, P_2 \geq 0 \ \forall\, i, i = 1,2, \dots ,45$$

Model 1: Turkish Air Force Flying Hour Program Problem Formulation with Lexicographic Goal Programming

Now, we can convert Model 1 to a weighted goal programming formulation. In Model 2, instead of prioritizing the decision variables and the deviation from the budget limit, we can minimize the weighted sum of the deviation variables, and consider the budget limit as a constraint ignoring the deviation variables for it. Hence, we can obtain an efficient frontier regarding budget versus the value we can achieve which can give more insight to the decision maker instead of one solution about the decision problem. This is explained in chapter 4 in detail.

$$\min Z = \sum_{i=1}^{45} w_i \, \mathrm{d}_\mathrm{i}^-$$

Subject to:

$$\frac{1 - e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1 - e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} + d_i^- = 1 \, , i = 1,2,\ldots,45$$

$$x_{i_{min}} \leq x_i \leq x_{i_{max}} \, , where \; i = 1,2,\ldots,45$$

$$\sum c_i x_i \; \leq g_B$$

$$x_i, w_i, d_i^- \geq 0 \;\; \forall \, i, i = 1,2,\ldots,45$$

Model 2: Turkish Air Force Flying Hour Program Problem Formulation with Weighted Goal Programming

where,

w_i *is the weight for mission i*

d_i^- *is negative deviation variable for mission i*

$x_{i_{min}}$ *is minimum number of flyinghours for mission i*

$x_{i_{max}}$ *is maximum number of flyinghours for mission i*

c_i *is cost per flying hour for mission i*

g_B *is budget limitation for our case for the given fiscal year*

3.3 Verification

Once we complete our model, we implement this to the decision problem for the Turkish Air Force Flying Hour Program as stated in this chapter. The Hierarchy Builder Software Version 2.0 (Weir, 2008) is used to build our decision model, which can be used with Microsoft Office Excel 2007 or older versions for the Value Focused Thinking part of our methodology. For the Goal Programming part, we used Visual Basic for Applications (VBA) for Excel to build a user interface to collect the required data from Hierarchy Builder Software Version 2.0 and that enables the user to enter the parameters to solve the problem. In addition, a simulation part is included in the code to give more insight about the problem to the analyst and to the decision maker. With this part, the analyst can perform many iterations for multiple budget limitations at the same time rather than solving the problem for one budget limitation at a time.

For the verification part, we ran the program at the extremes of the budgets. We ran with a buget such that the model could only choose flying hours at their minimum and then a very large budget so that it could choose flying hours at their maximums. In both cases the model behave appropriately. To determine how many points would be necessary to determine the efficient frontier, we ran the model ten times by changing the number of iterations from 10 to 1000 while holding the other parameters the same then compared the results. At the end of the analysis, we expected to see an increasing function with a decreasing return to scale in all of the graphs for the overall value versus cost representing the efficient frontier. When we look at the results for different number of iterations, we always obtain this function meaning that our model and VBA code works properly.

In the next chapter, application of the methodology to the Turkish Air Force Flying Hour Program with the original scenario and different possible scenarios are presented with the analysis, results and validation.

IV. Results and Analysis

This chapter explains the results and analysis obtained from the application of the methodology presented in chapter 3 to the Turkish Air Force Flying Hour Program. First, the inputs that are required for the model are explained. Next, the provided outputs of the model are discussed. This is then followed by some sensitivity analysis and post analysis. Finally, the validation of the methodology is explained.

The analysis in this research is performed on a computer with Microsoft Windows 7 Enterprise, Service Pack 1, 2.70 GHz, AMD Athlon(tm) 2 X2 215 Processor, 4.00 GB RAM, , 64-bit Operating System. The results are analyzed in Microsoft Office Excel 2007.

4.1 Inputs and Outputs

The implementation of the methodology for the Turkish Air Force Flying Hour Program requires certain inputs. Some of these inputs need an interaction with the decision maker, and this is completed as indicated in chapter 3 while formulating the value focused thinking portion of this research. For the goal programming portion of the model, we make use of Visual Basic for Applications (VBA) for Excel to simplify the usage of the methodology by building a user interface which is shown in Figure **10**.

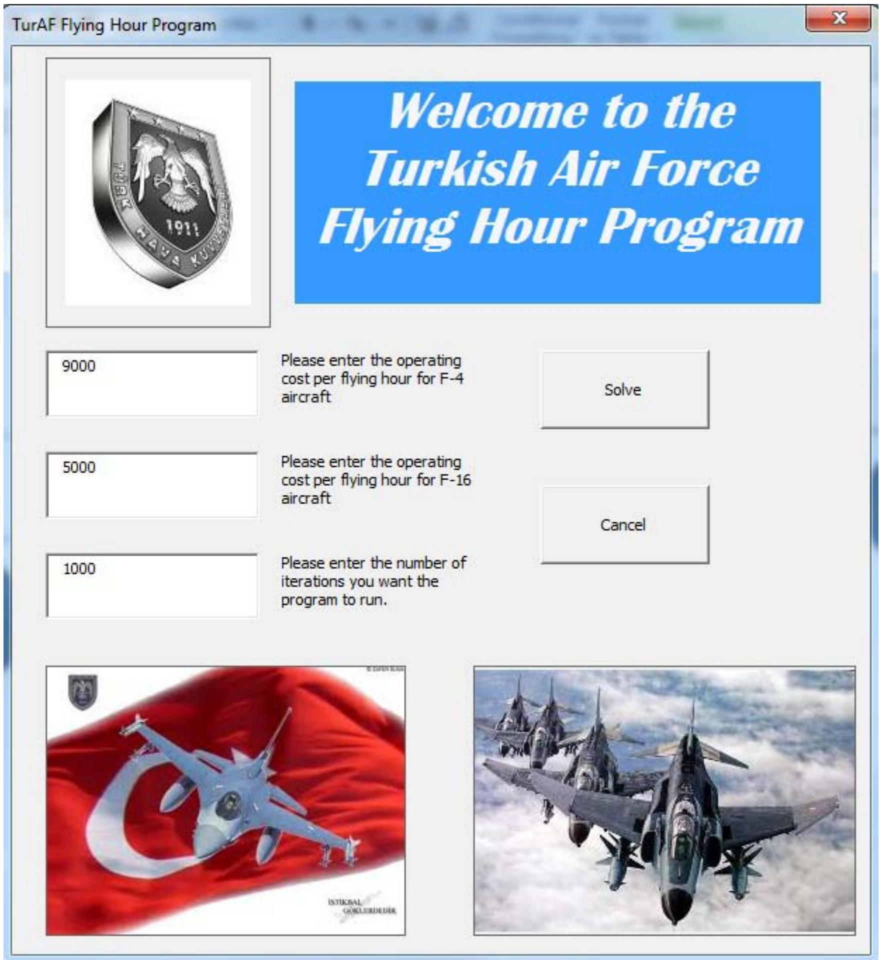


Figure 10 User Interface for TurAF Flying Hour Program.

The user interface takes the values for the costs of operating hours of each aircraft and the number of iterations that the user wants the simulation to run. Notice that the maximum budget to get the value of one for the flying hours depends on the operating costs of the aircraft, which may be subject to change each year. Therefore, this interface allows the user to enter these values for each aircraft before starting to the analysis.

The VBA code created in addition to the Hierarchy Builder Software Version 2.0 (Weir, 2008) allows us to start with the highest budget limitation which is calculated from the inputs of operational costs of each aircraft as seen in the equation 19. This enables us to start with a deviation of zero from our overall goal supplying us a value of one for that budget which means we are achieving 100% of the maximum number of flying hours of each mission. In addition, it calculates the minimum required budget that gives us a value of zero, which means we are achieving 100% of the minimum number of flying hours of each mission. Finally, by taking the number of iterations that the user wants the program to run, we can calculate a value, y, from equation 20 to decrease from the maximum budget for a given number of iterations until we obtain the minimum budget.

$$y = \frac{\left(\sum_{i=1}^{30} x_{i_{max}} c_{F-16} + \sum_{i=30}^{45} x_{i_{max}} c_{F-4}\right) - \left(\sum_{i=1}^{30} x_{i_{min}} c_{F-16} + \sum_{i=30}^{45} x_{i_{min}} c_{F-4}\right)}{NumIte} \quad (20)$$

where,

$x_{i_{max}}$ $is\ maximum\ number\ of\ flying\ hours$

$x_{i_{min}}$ $is\ minimum\ number\ of\ flying\ hours$

c_{F-16} $is\ operating\ cost\ for\ F-16\ aircraft$

c_{F-4} $is\ operating\ cost\ for\ F-4\ aircraft$

$y\ is\ monetary\ value\ for\ increments\ of\ the\ budget$

$NumIte\ is\ the\ number\ of\ iterations\ for\ simulation\ to\ run$

This allows us to see the behavior of the system under changing conditions as in the algorithm below. Hence, we can obtain a graph that shows the efficient frontier for the overall value versus cost where we can see the percentage of the achievement to the corresponding available budget as in Figure 12.

$For\ i = 1\ to\ NumIte$

$$\left(\sum_{i=1}^{30} x_{i_{max}} c_{F-16} + \sum_{i=30}^{45} x_{i_{max}} c_{F-4}\right) - \ (i * y) \geq \ \sum_{i=1}^{30} x_{i_{min}} c_{F-16} + \sum_{i=30}^{45} x_{i_{min}} c_{F-4}$$

$Next\ i$

After the program starts to run, it acquires the necessary parameters from the user and Hierarchy Builder Software Version 2.0. Then, it builds the spreadsheet for goal programming as in Figure **11**. In this spreadsheet, first the program puts the value for maximum budget in the cell for Total Budget and solves the formulation by using Excel Solver 2007. It then records the results of this run to another spreadsheet. On the second run, it subtracts the calculated value of *y* from the previous budget, then runs again, and keeps this process until it finishes the defined number of iterations.

On the spreadsheet for the results of each run, we can see our final outputs as deviation from the overall value, number of flying hours of each mission and their corresponding budget limitations. Then the VBA code modifies this spreadsheet for the analyst to perform many types of analyses according to the needs of the decision maker. Some examples for the possible analyses that the decision maker may wish to see are performed in the following sections.

BELOW	MISSIONS	WEIGHTS	RHO	MIN	MAX	FUNCTION	DEVIATION	FLYING HOURS	COST PER AIRCRAFT
Air to Air Squadrons (AAT)	AAM1	0.064837565	266.3729492	4282	4988	-10308146.64	10308147.64		$5,000.00
Air to Air Squadrons (AAT)	AAM2	0.044362544	737.4017826	13384	15164	-83799647.93	83799648.93		$5,000.00
Air to Air Squadrons (AAT)	AAM3	0.068250068	211.2403442	948	1484	-95.47299328	96.47299328		$5,000.00
Air to Air Squadrons (AAT)	AAM4	0.054600055	119.5606293	789	1078	-805.2892523	806.2892523		$5,000.00
Air to Air Squadrons (AAT)	AAM5	0.02047502	162.4935196	732	1035	-105.8507745	106.8507745		$5,000.00
Air to Air Squadrons (AGT)	AGM1	0.013118195	312.6190361	1065	1850	-31.74257681	32.74257681		$5,000.00
Air to Air Squadrons (AGT)	AGM2	0.008526827	493.7250901	1776	2640	-42.95934081	43.95934081		$5,000.00
Air to Air Squadrons (AGT)	AGM3	0.003279549	219.44035	450	840	-8.151569917	9.151569917		$5,000.00
Air to Air Squadrons (AGT)	AGM4	0.010494556	261.1123474	308	890	-2.524745212	3.524745212		$5,000.00
Air to Air Squadrons (AGT)	AGM5	0.009182736	271.8459567	22	590	-0.096198457	1.096198457		$5,000.00
Air to Air Squadrons (AGT)	AGM6	0.005903188	760.8664831	1663	2537	-11.56247389	12.56247389		$5,000.00
Air to Air Squadrons (Night)	N1	0.055821372	361.1779645	982	1730	-16.20630816	17.20630816		$5,000.00
Air to Air Squadrons (Night)	N2	0.044657097	298.4430723	554	1302	-5.879591309	6.879591309		$5,000.00
Air to Air Squadrons (Other)	O1	0.043062201	455.0328641	554	1302	-2.948464422	3.948464422		$5,000.00
Air to Air Squadrons (Other)	O2	0.04784689	358.7248744	0	621	0	1		$5,000.00
F-16 (AAT)	AAM6	0.007113387	427.4513596	1287	1979	-24.07462741	25.07462741		$5,000.00
F-16 (AAT)	AAM7	0.00569071	262.4803118	925	1468	-37.68352573	38.68352573		$5,000.00
F-16 (AAT)	AAM8	0.004623702	39.28668943	232	316	-414.8848666	415.8848666		$5,000.00
F-16 (AAT)	AAM9	0.006402049	38.70457821	346	407	-9614.713326	9615.713326		$5,000.00
F-16 (AAT)	AAM10	0.001422677	51.3133442	232	316	-112.919576	113.919576		$5,000.00
F-4 (AAT)	AAM11	0.0055348	59.55516075	316	447	-225.5434004	226.5434004		$9,000.00
F-4 (AAT)	AAM12	0.0069185	1030.602468	6510	8368	-661.8297412	662.8297412		$9,000.00
F-4 (AAT)	AAM13	0.001729625	1105.028666	7820	9826	-1413.135879	1414.135879		$9,000.00
F-4 (AAT)	AAM14	0.004497025	506.5332749	865	1652	-5.727306087	6.727306087		$9,000.00
F-4 (AAT)	AAM15	0.006572575	422.1377486	1395	2205	-30.75167738	31.75167738		$9,000.00
F-16 (AGT)	AGM7	0.017825312	506.5332749	865	1652	-5.727306087	6.727306087		$5,000.00
F-16 (AGT)	AGM8	0.029708853	414.6885555	1425	2165	-36.13951713	37.13951713		$5,000.00
F-16 (AGT)	AGM9	0.028223411	797.4394964	4264	6035	-234.4420916	235.4420916		$5,000.00
F-16 (AGT)	AGM10	0.023767083	975.4237181	6504	8275	-938.4375947	939.4375947		$5,000.00
F-16 (AGT)	AGM11	0.005941771	248.6345888	1049	1603	-75.053582	76.053582		$5,000.00
F-16 (AGT)	AGM12	0.020796197	756.3883723	5575	6877	-1933.222635	1934.222635		$5,000.00
F-4 (AGT)	AGM13	0.020796197	320.7911089	1730	2477	-242.4675375	243.4675375		$9,000.00
F-4 (AGT)	AGM14	0.019310755	436.2614551	1470	2344	-32.44065075	33.44065075		$9,000.00
F-4 (AGT)	AGM15	0.026737968	186.4042693	1706	2180	-10238.91138	10239.91138		$9,000.00
F-4 (AGT)	AGM16	0.029708853	270.6477957	1885	2416	-1230.685901	1231.685901		$9,000.00
F-4 (AGT)	AGM17	0.023767083	486.7201232	1963	3058	-61.96982867	62.96982867		$9,000.00
F-4 (AGT)	AGM18	0.005941771	414.9569535	2126	3165	-181.7722186	182.7722186		$9,000.00
F-16 (Night)	N3	0.028497397	538.6487249	3777	5078	-1217.64689	1218.64689		$5,000.00
F-16 (Night)	N4	0.033526349	348.7779281	1283	2031	-43.7079787	44.7079787		$5,000.00
F-4 (Night)	N5	0.026821079	11.98054608	567	610	-3.68044E+20	3.68044E+20		$9,000.00
F-4 (Night)	N6	0.022797918	13.94716565	567	600	-4.99293E+17	4.99293E+17		$9,000.00
F-16 (Other)	O3	0.024570025	28.85843619	530	610	-100944466.1	100944467.1		$5,000.00
F-16 (Other)	O4	0.020884521	28.85843619	530	610	-100944466.1	100944467.1		$5,000.00
F-4 (Other)	O5	0.023923445	281.4416211	982	1730	-34.1533809	35.1533809		$9,000.00
F-4 (Other)	O6	0.0215311	53.46106384	621	748	-122209.5856	122210.5856		$9,000.00

OBJECTIVE VALUE		
0		
BUDGET LIMIT	<=	TOTAL BUDGET
0	<=	$550,000,000.00

Figure 11 Goal Programming Spreadsheet

4.1.1 Parametric Analysis (Overall Value versus Cost)

For parametric analysis, since the output is the deviation from the overall value, we have to convert it to the value for the corresponding budget simply by subtracting it from 1. Notice that as stated in the assumptions part of chapter 3 since there is no available budget data for our case, we used random budget data. Operating costs for an F-4 is taken to be $9000 (Formerspook Blog Web site, 2007), and for an F-16 it is $5000 (National Training and Simulation Association (NTSA) Web site). After running the program, we obtain the function in Figure 12,

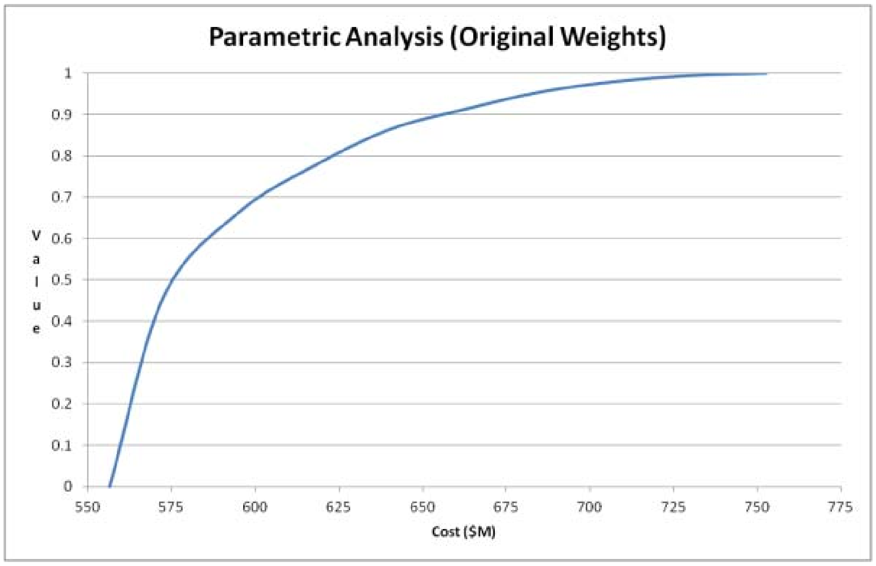


Figure 12 Parametric Analysis for Original Weights

According to this function, we can see what percentage of the maximum number of total flying hours we can achieve with the corresponding budget limitation. Notice that, in our case we have a minimum number of flying hours for each mission that should be completed that cost around $556 M and has a value of zero. Therefore, according to the graph we see that we can achieve 80% of the overall flying hours with $640 M budget when we spend $84 M more than the minimum budget, and 90% of the flying hours with a $665 M budget when we spend $109 M more to the minimum budget.

On the other hand, the required budget is $752 M to obtain 100% achievement in flying hours and we have to spend another $87 M to achieve 10% more in addition to the 90% achievement with a $109 M budget. Consequently, by looking at this graph, the decision maker should evaluate whether achieving 90% of the flights are enough for the Air Force, which saves about a $90 M budget, or to achieve the other 10% is also as valuable as the first 90% portion of the flying hours.

However, the analyst can consider giving this parametric analysis to the decision maker as a good insight for the decision problem; it may not be enough in this level when you talk about million-dollar budgets. Therefore, we may look for some other analysis to give more insight to the decision maker.

4.1.2 Flying Hours versus Cost

Since we are dealing with value-focused thinking giving importance to the decision maker's values, the parametric analysis is the focus of our case. However, when we show the graph in Figure 12 to the decision maker it may not provide as good insight as we think it should. For instance, the decision maker may find achieving 80% is satisfactory for this fiscal year and that can be accomplished by spending only about $84 M more than the minimum required budget. This decision may change when the decision maker sees the distribution of the flying hours with this amount of budget. Therefore, from our model we can derive another graph from the data to give more insight to the decision maker about the distribution of the flying hours. This graph in Figure 13 makes it more clear for the decision maker to see how many flying hours the Turkish Air Force can obtain with the given budget for each task (Air to Air, Air to Ground, Night, and Other).

In Figure 13, we see the distribution of the flying hours for each type of task for a given budget. In the graph, for all tasks the flying hours increase with the increasing budget. With the $640 M budget where we could achieve 80% of the total flying hours, we can fly 43517 hours from air to air tasks, 42167 hours from air to ground tasks, 10709 hours from night tasks, and 5230 hours from other tasks. If we increase the budget to

$665 M, we can fly 43980 hours from air to air tasks, 44820 hours from air to ground tasks, 10900 hours from night tasks, and 5440 hours from other tasks. From the difference that a $25 M budget creates in terms of flying hours for each type of task, we only see a significant increase in air to ground tasks. Before making comments on this issue it may be beneficial to indicate that according to the hierarchy, we see that air to ground tasks includes more missions and requires more flying hours which increases its cost when compared to the other types (air to air, night and other tasks).

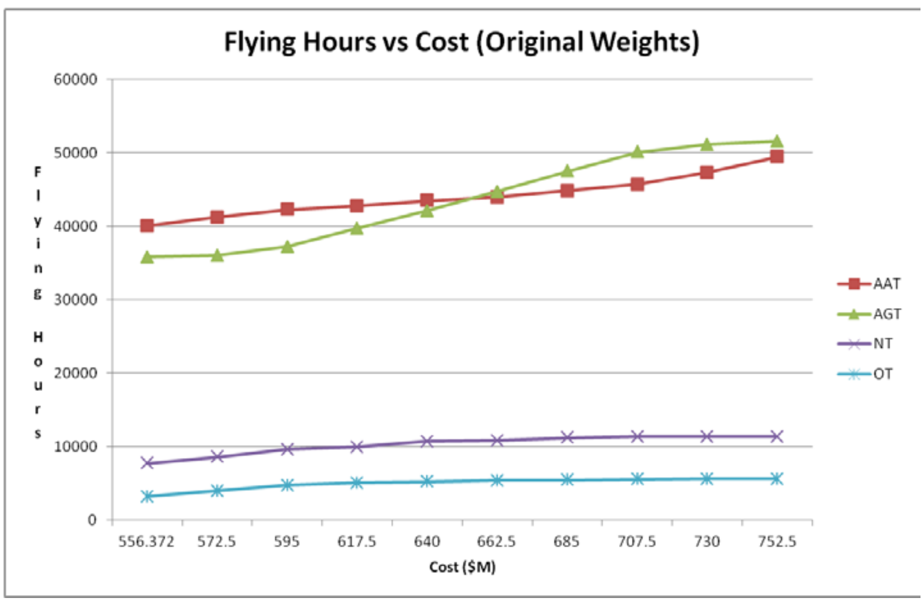


Figure 13 Flying Hours versus Cost for Original Weights

Under these circumstances, the decision maker may wish to keep overall achievement at 80%, or may want to increase it to 90% while considering overall value and the flying hours for the available budget at the same time.

4.1.3 Individual Values for Flight Tasks versus Cost

While, the parametric analysis provides a good insight for the percentage of achievement we can attain with our budget; we may want to see how well we do in terms of values individually for the type of tasks. Because there may be a case, where we seem to achieve an 80% of our overall value, but when we look at the tasks individually, we may be achieving 90% of three of the tasks and 10% of one of the tasks. Hence, the decision maker may wish to see an evenly distributed graph rather than this kind of a scenario or may find it satisfactory.

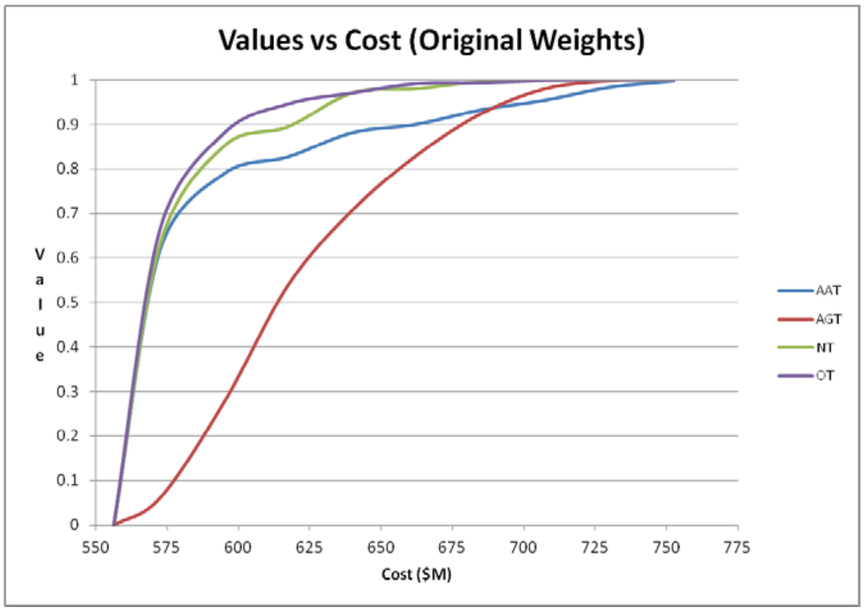


Figure 14 Individual Values versus Cost for Original Weights

This analysis may not be useful when the budget is enough to achieve at an average of 90% from each task. Nevertheless, it may provide a good illustration for the distribution of the percentages representing the achievement of individual tasks when we have smaller amount of budgets. As you can see from Figure 12, when we have $595 M budget, we can achieve 66% for the overall value, which may be satisfactory for the decision maker for this amount of budget. On the other hand, according to the Figure 14, we can only achieve 27% of the air to ground tasks, where we can achieve 80% of the air-to-air, 87% of the night and 90% of the other tasks. Hence, this graph may not be the case that the decision maker wishes to see for the distribution of the individual tasks. We can perform some post analysis to overcome this issue to get more evenly distributed values when this kind of a case occurs. This post analysis is explained in detail in section 4.3.

4.2 Sensitivity Analysis

It is mentioned in the previous section that we can see the behavior of our problem under changing parameters like budget or costs of missions by obtaining the efficient frontier for overall value versus cost, and their corresponding flying hours. Now we can perform some other analysis to see if our problem is sensitive to small changes in weights. Recall that in our value hierarchy we have local weights and the global weights that we elicit from the decision maker. Therefore, we do some analysis on these weights by changing them and observe how they affect our original solution.

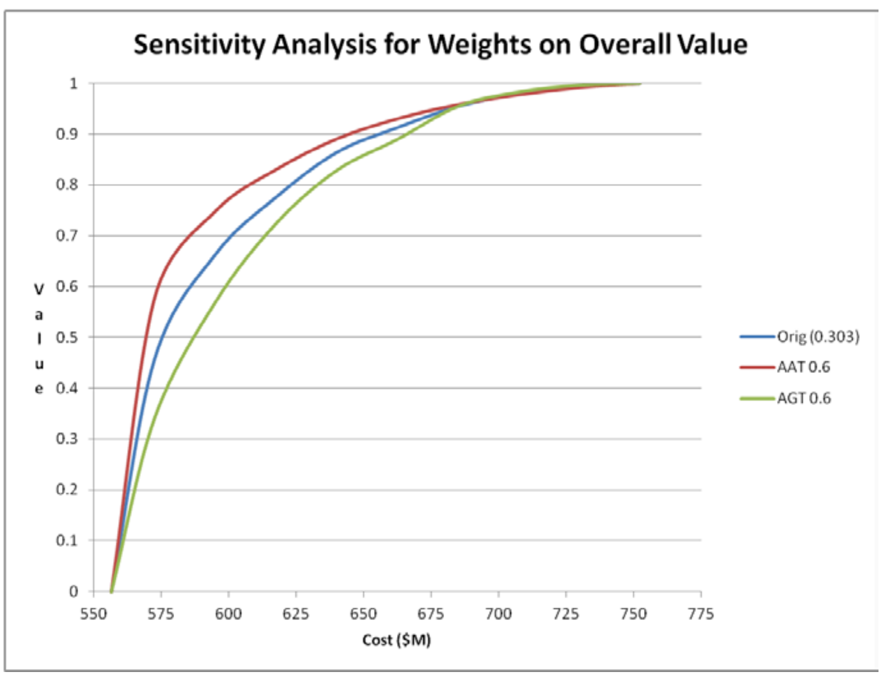


Figure 15 Sensitivity Analysis for Weights on Overall Value

We perform this analysis by changing all local weights of each type of flight tasks (air to air, air to ground, night and other) by making the task's weight under consideration first 0.6 and then 0.1. We arranged the others either increasing or decreasing proportionally while making this change to obtain reasonable results rather than a total change in weighting. For the brevity of this section, we only show the results for the two scenarios when air to air and air to ground tasks get weights 0.6 versus the original weights.

You can see from Figure 15 when we change air to air task's weight to 0.6 from 0.303 and reduce others' weighting proportionally to the original weights, the overall value increases for the budget between \$565 M and \$665 M. On the other hand, when we change air to ground task's weight to 0.6 from 0.303 and reduce others' weighting proportionally to the original weights, the overall value decreases for the budget between \$565 M and \$665 M. If we look at the graphs for other task types where we change weights in the same manner, we see similar results. Therefore, we can conclude that the overall value is sensitive to the changes in weights of tasks. Different quantity of missions included in each type of tasks, the required flying hours and their associated costs, and the global weights of each mission can cause the overall value to be sensitive to weighting. As we see from Figure 15 if we give more importance to air to ground task, it reduces our overall value, because there are more missions and more flying hours, which cost more than the other type of tasks to TurAF. Thus, the program tries to make these missions' values one prior to the others that reduces our overall value.

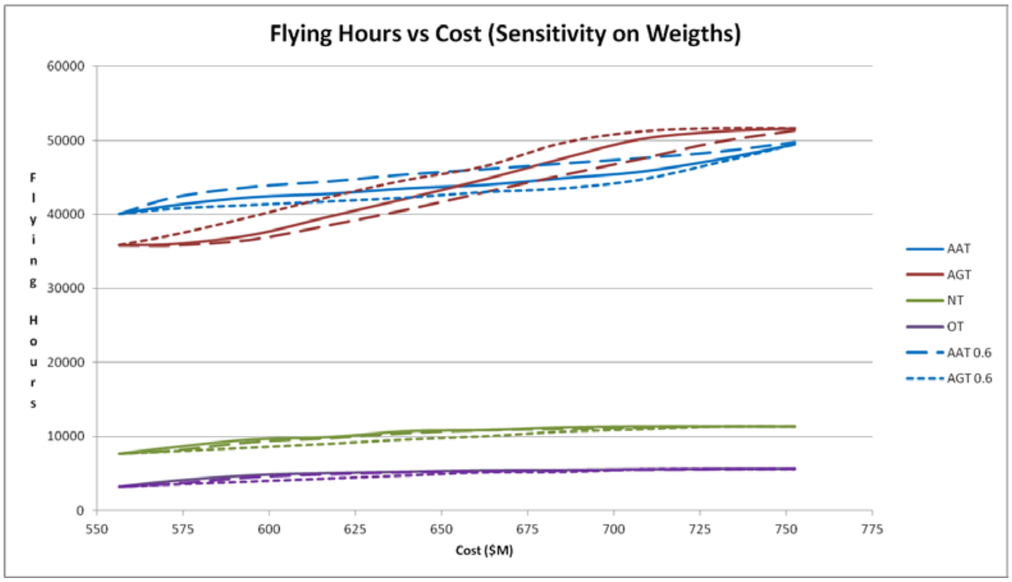


Figure 16 Sensitivity Analysis for Weights on Flying Hours

Once we observe this issue, we can now check if this makes any difference in terms of flying hours and help the decision maker to think about the trade-offs between them. We can see by looking at Figure 16 that the decision maker should consider weighting more carefully, because it causes some differences in terms of flying hours. In order to illustrate Figure 16 more clearly, we can redraw air to air versus air to ground tasks in Figure 17, and night versus other tasks in Figure 18 individually by changing the scale of the graphs for flying hours.

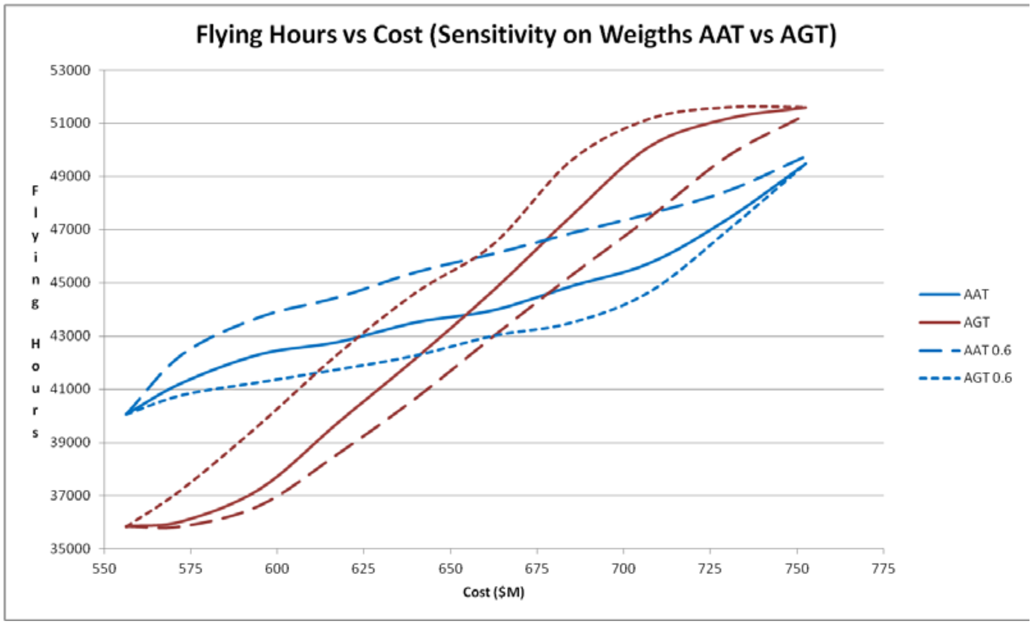


Figure 17 Sensitivity Analysis for Weights on Flying Hours (AAT versus AGT)

From Figure 17, we see that giving more importance to air to air tasks increases the number of flying hours for air to air tasks we can get with the corresponding budget while decreasing the flying hours for air to ground tasks with the same amount of budget and vice versa. In addition, we see that we can buy more air to air flying hours than air to ground until $660 M with original weights. This point changes according to the weighting to $610 M when air to ground is more important, and $710 M when air to air is more important.

On the other hand, we can see from Figure 18 giving more importance to air to air tasks reduces, but doesn't change much in flying hours for both night and other tasks. However, giving more importance to air to ground tasks affects and reduces the flying hours we can buy for these more.

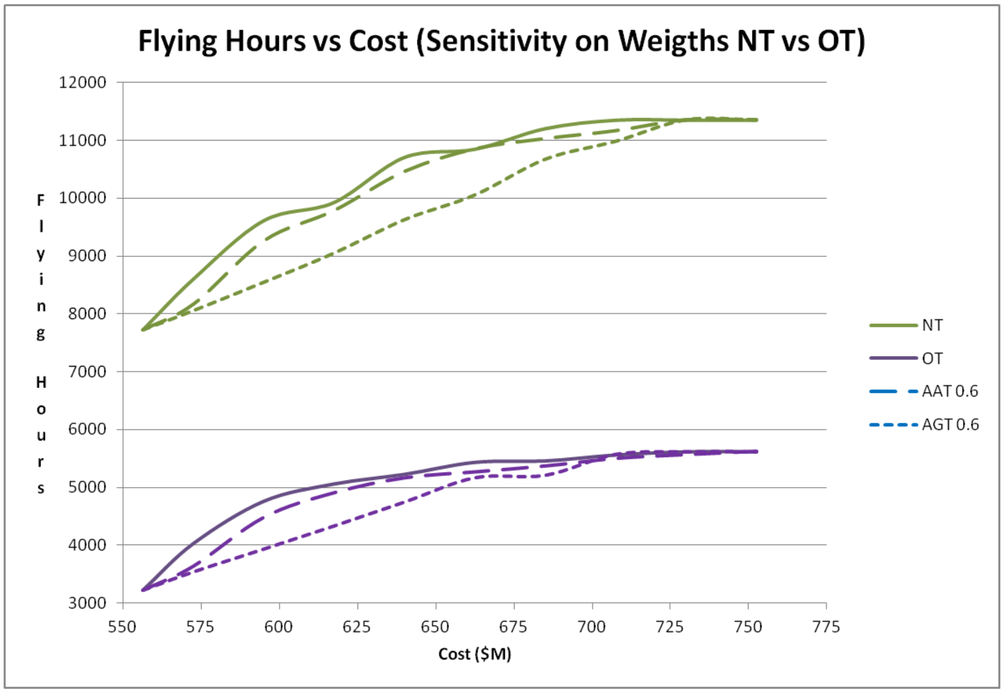


Figure 18 Sensitivity Analysis for Weights on Flying Hours (NT versus OT)

Notice that we can expand this analysis on every tier of the hierarchy to see how sensitive the system is according to those changes as well. The analyst can decide to perform any kind of sensitivity analysis according to the decision maker's directions or demand.

4.3 Post Analysis

It is obvious that we always want to maximize our overall value with the given budget. From Figure 12, we can achieve 66% of the overall goal when we have $595 M budget. This result may be satisfactory for the decision maker for this amount of budget. On the other hand, from Figure 14, we see that the distribution of the flight tasks we can achieve with lower budgets can be distributed unevenly which may be a concern for the decision maker. If we recall, according to the Figure 14, we can only achieve 27% of the value for the air to ground tasks, where we can achieve 80% of the air-to-air, 87% of the night and 90% of the other tasks with a $595 M budget. By looking at this picture, the decision maker may wish to increase the value for Air to Ground to a certain level where decreasing the other values may be also satisfactory for him/her. We can overcome this issue by modifying our Goal Programming formulation by adding some constraints for the values that should be examined which in our case is Air to Ground tasks. Consequently, we can give more insight about the results to the decision maker.

Because our example is about air to ground tasks, we modify the formulation to observe how changing the overall value affects the value of air to ground tasks and vice versa. We can also specify the importance of air to ground tasks versus all others (air to air, night and other tasks), by including weighting in the objective function of the formulation. Notice that, this modification can be used for other tasks by changing the corresponding values if the decision maker wants to see the behavior of them as well.

First, we start by modifying our original objective function for goal programming which is a part of the new objective function for this formulation as in equation 21,

$$Z' = \sum_{i=1}^{45}(w_i \, \mathrm{d}_\mathrm{i}^-) - \left(\sum_{i=6}^{11}(w_i \, \mathrm{d}_\mathrm{i}^- + \sum_{i=26}^{37}(w_i \, \mathrm{d}_\mathrm{i}^-)\right) \qquad (21)$$

Then we can add equation 22 for our goal we want to achieve for air to ground tasks. In this equation, we are calculating the values for air to ground tasks with their corresponding weights, and then we normalize them by dividing all to the sum of weights for air to ground tasks.

$$g_{AGT} = \frac{\left(\sum_{i=6}^{11} w_i \frac{1-e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1-e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} + \sum_{i=26}^{37} w_i \frac{1-e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1-e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}}\right)}{\sum_{i=6}^{11} w_i + \sum_{i=26}^{37} w_i} \qquad (22)$$

Finally, in equation 23, we can add another constraint for the overall value. We use this constraint to see the behavior of the overall value versus air to ground tasks. This constraint can be obtained simply by calculating the values for all missions and their corresponding weights;

$$V(x) = \sum_{i=1}^{45} w_i \frac{1-e^{\left[-\frac{x_i - x_{i_{min}}}{\rho}\right]}}{1-e^{\left[-\frac{x_{i_{max}} - x_{i_{min}}}{\rho}\right]}} \qquad (23)$$

After having these equations, now we can write our new objective function where we can assign a value for air to ground tasks we want to achieve. Assigning this value to air to ground tasks makes the program first try to achieve that value, than try to achieve other tasks depending on weighting. We can do this by adding a constraint where g_{AGT} will be greater than or equal to the assigned value and solve the formulation again.

The objective is now to minimize the summation of the deviation from our goal for air to ground tasks and the deviation from our goal for all other tasks (air to air, night, and other tasks).

min Z $= t_1(1 - g_{AGT}) + (1 - t_1)Z'$

Subject to:

$x_{i_{min}} \leq x_i \ , where\ i = 1,2, \dots ,45$

$x_i \leq x_{i_{max}} , where\ i = 1,2, \dots ,45$

$V(x) \geq V(x)'$

$g_{AGT} \geq g'_{AGT}$

$$\sum_{i=1}^{45} c_i x_i \leq g_B$$

$$v_i(x_i) + d_i^- = 1$$

$$x_i \geq 0 \ \forall \, i, i = 1,2, \dots, 45$$

Model 3: Modification of Goal Programming for Air to Ground Tasks

where,

$Z' \, is \, the \, modified \, objective \, function \, regarding \, to \, the \, value \, to \, be \, analyzed \, for \, AGT$

$g_{AGT} \, is \, the \, value \, calculated \, for \, air \, to \, ground \, tasks$

$g'_{AGT} \, is \, the \, value \, we \, want \, to \, achieve \, for \, the \, air \, to \, ground \, tasks$

$t_1 is \, the \, weight \, for \, air \, toground \, tasks$

$g_B \, is \, budget \, limitation \, for \, our \, case \, for \, the \, given \, fiscal \, year$

d_i^- is $deviation \, variable \, for \, mission \, i$

c_i $is \, cost \, per \, flying \, hour \, for \, mission \, i$

$x_{i_{min}} \, is \, minimum \, number \, of \, flyinghours \, for \, mission \, i$

$x_{i_{max}} \, is \, maximum \, number \, of \, flyinghours \, for \, mission \, i$

$w_i \, is \, the \, weight \, for \, mission \, i$

$V(x) \, is \, overall \, value \, for \, all \, missions \, to \, the \, corresponding \, budget$

$V'(x) \, is \, the \, new \, overall \, value \, we \, want \, to \, achieve$

For the illustration of this analysis, we first start with, $V'(x) = 0.66$, $g'_{AGT} = 0, t_1 = 1$, with the budget limit $g_B = \$595$ M. After obtaining the new results for these values, we then continue to the process reducing $V'(x)$ by 0.03 for each run until

$V'(x) = 0.57$ as shown in Figure 19. Then, we obtain the results for each run as presented in Figure 20 and Figure 21.

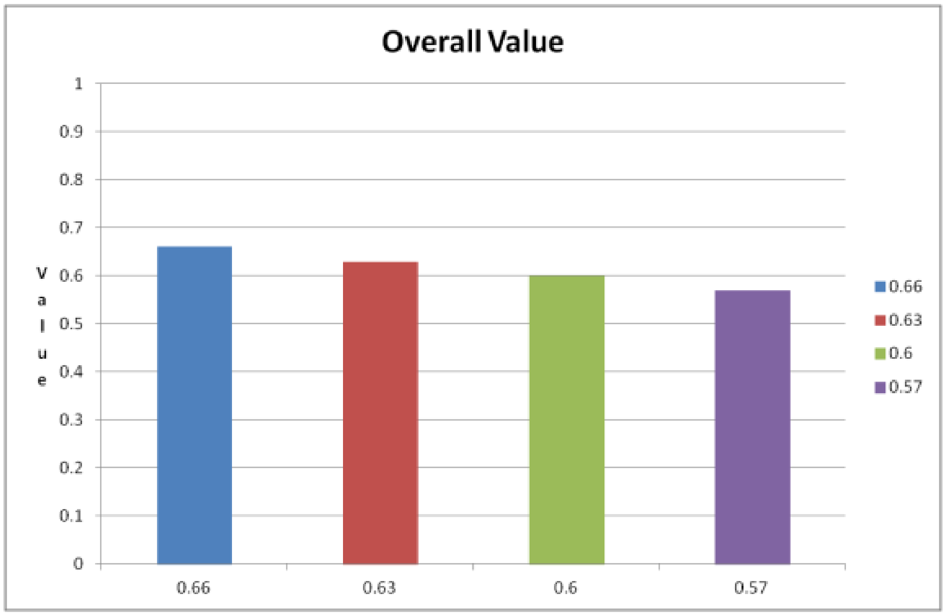


Figure 19 Changing Overall Value for Four Runs

Notice that these graphs are obtained under the conditions where we want to achieve as much as possible for the air to ground tasks by giving a value for weights 1 to air to ground and 0 to all other tasks (air to air, night, and other tasks). In addition, relaxing the value constraint for air to ground tasks by $g'_{AGT} = 0$ allows us to see the maximum value we can achieve under given conditions.

From Figure 20, we see that reducing the overall value in each run reduces the values for air to air, night and other tasks, but increases the value for air to ground tasks. Thus, the decision maker can make some tradeoffs by looking at this graph how he/she wishes to have a distribution among the flight tasks.

Similar to the statement according to Figure 20, by looking at Figure 21, the decision maker can see the corresponding flying hours to the values obtained from each run. Therefore, he/she can gain some more insights how values affect the flying hours.

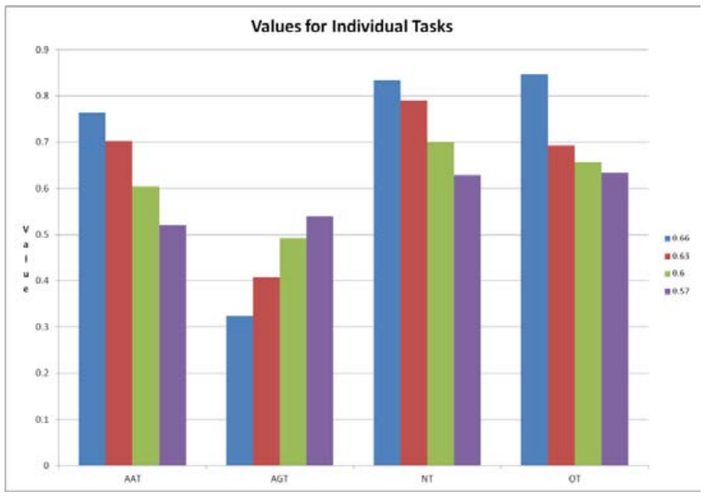


Figure 20 Changes in Values for Individual Tasks Corresponding to the Change in the Overall Value

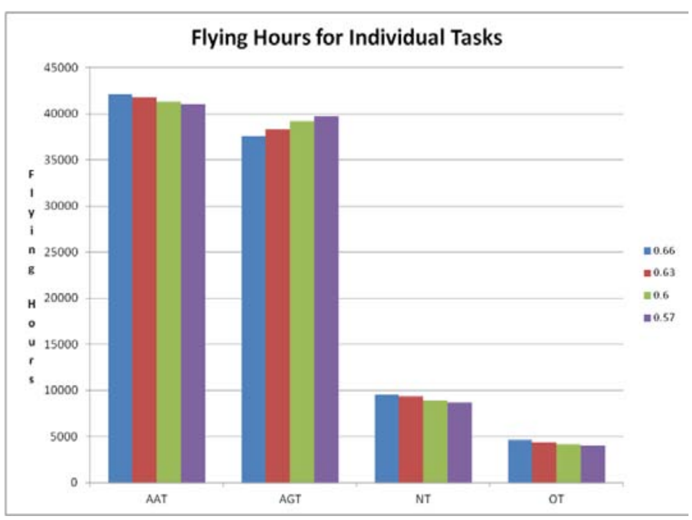


Figure 21 Changes in Flying Hours for Individual Tasks Corresponding to the Change in the Overall Value

In this scenario, we can observe that from Figure 22, reducing the overall value by 9% gives us more evenly distributed values among all tasks. Therefore, if we just give up 9% of our overall value, we can increase our value for air to ground tasks by 27%, which may be more desirable in terms of combat readiness level with a \$595 M budget.

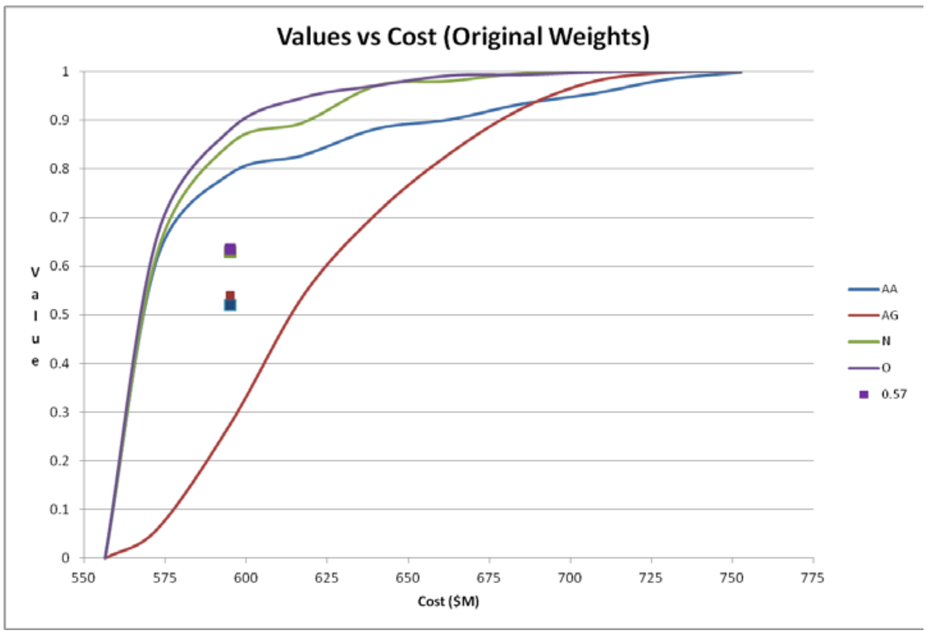


Figure 22 New Distribution of the Individual Values when Overall Value is 0.57

If we want to do a second analysis where we want to see the behavior when the decision maker gives weights equally to the importance of air to ground tasks versus others (air to air, night, and other tasks). This time, we hold the other values the same but make $t_1 = 0.5$. Then, we obtain the results for each run as presented in Figure 23 and Figure 24.

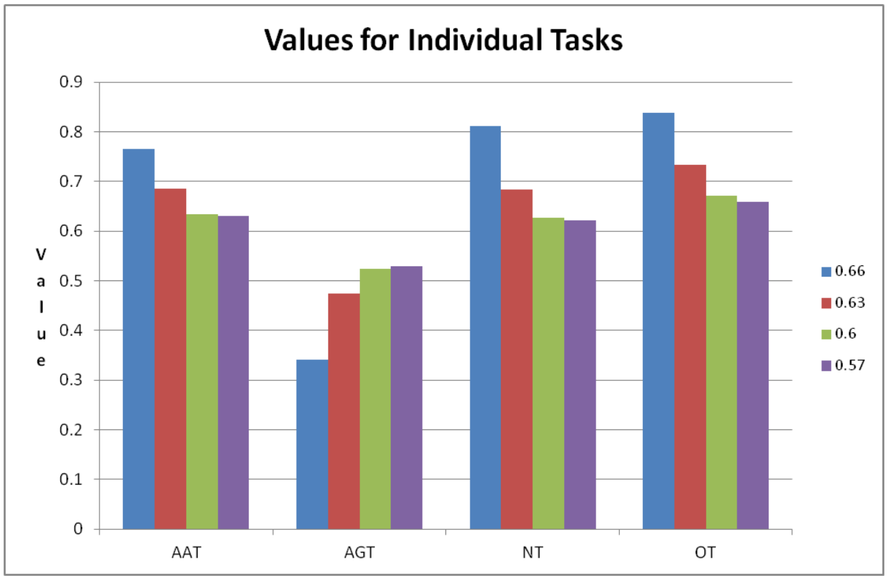


Figure 23 Changes in Values for Individual Tasks Corresponding to the Change in the Overall Value (Equal Weights)

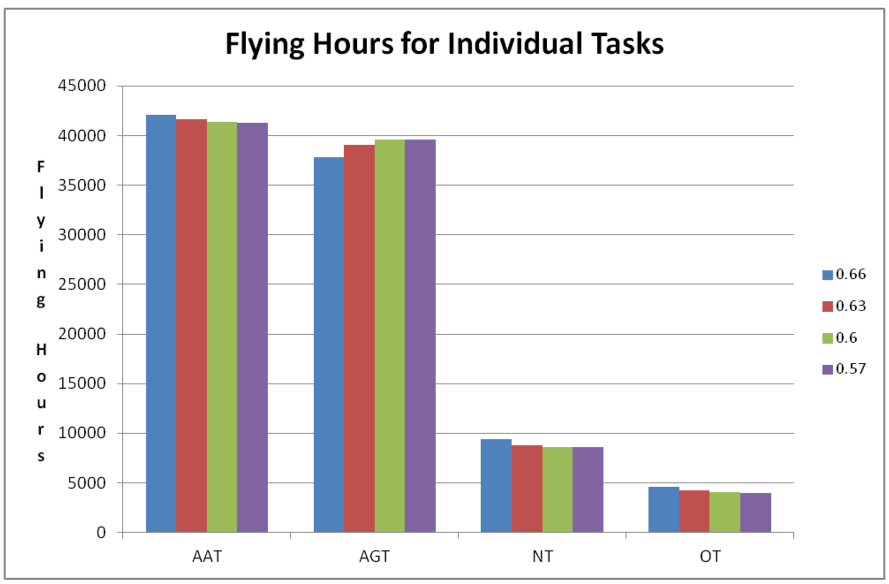


Figure 24 Changes in Flying Hours for Individual Tasks Corresponding to the Change in the Overall Value (Equal Weights)

In this scenario, if the decision maker gives equal weights meaning that achieving air to ground tasks are as important as achieving the other three tasks, we still have an increase by 25% and can achieve 52% of the value for air to ground tasks, by only decreasing 6% of the overall value as shown in Figure 23.

If we want to examine another scenario where we give all importance to air to ground tasks $t_1 = 1$, and setting the constraints $g'_{AGT} = 0.5\ and\ V(x)' = 0$, we see that we can achieve 70% of the value for our air to ground tasks where we cannot achieve any other tasks which gives us only 21% achievement for the overall value with a $595 M budget.

As you see from these three scenarios, we can do these kinds of analyses for other values with different types of parameters changing to the preferences of the decision maker. It is evident that if we have more budgets, then we do not have to concern about this analysis. For instance, if we have $665 M we can achieve 90% of the value for all our tasks. Therefore, the decision maker does not have to concern about these trade-offs in the decision situation.

4.3 Validation

For the validation part, Microsoft Office Excel 2007 spreadsheet created according to the data provided by the TurAF Headquarters including the model with Hierarchy Builder Software Version 2.0 is sent to the department. The department states that the model complies with the decision problem requirements and conforms to the conceptual description.

In this chapter, we created our methodology by using VFT as a constraint in a goal programming model. Then, we illustrated how we can use this methodology in a case study for Turkish Air Force Flying Hour Program. Then, we explain how we can perform some analyses on the results, which may be useful to give more insight to the decision maker. Notice that once we obtain the spreadsheet for results according to the inputs, we can perform much analysis according to the directions and the demand of the decision maker by using Microsoft Excel. In the next chapter, we explain the summary and the conclusions derived from this research. Finally, we propose some recommendations for future research.

V. Summary and Conclusion

In this chapter, we first provide a brief summary, and then explain the conclusions derived from this research. Finally, we propose some suggestions for possible future work.

5.1 Summary of the Research

In the first chapter of this research, the problem is defined. Research objectives, questions, and assumptions are stated.

Chapter 2 discusses the definition of a decision, and explains the foundations of decision analysis. Then, the methods to solve multi criteria and multi objective decision analysis problems are explained. VFT and its ten-step process are described. Next, a broad explanation of goal programming modeling is presented. Finally, we give details about the contribution of this research.

In chapter 3, we examined a case study for our methodology, the Turkish Air Force Flying Hour Program. We begin with explaining the background of the problem, and then state the objectives and assumptions belonging specifically to this case in order to implement our methodology. The solution methodology goes through steps starting with VFT by building the value hierarchy, then determining the evaluation measures and the functions, and weighting the hierarchy by using the swing weight method. These steps are done according to the decision maker's values and preferences. Afterward, it takes the value model and uses it as a constraint in a goal programming formulation by setting a goal for the combat readiness level with some budget constraint. Finally, the verification of the model is discussed.

We discuss the obtained results and provide some insight about what kind of analysis we can perform on these results in chapter 4. We explain how to graph the efficient frontier for the overall value and individual values versus cost and analyze them as well as the flying hours versus cost graph. In addition, we perform some sensitivity analysis on weights to see how the system behaves under these changes in weights. Furthermore, we perform some post analysis on the individual values. In this case, we are able to observe how we do for tasks individually for lower amount of budgets. Therefore, if an uneven distribution occurs we can prevent this situation by balancing them.

In this chapter, conclusions from the results are presented, some suggestions for future work are proposed.

5.2 Conclusions

It is hard to make a decision when you have a complex system with multiple conflicting objectives, and large numbers of changing parameters with different data types. Especially, if this decision affects a large number of people, a strategically important aspect of a country, and a large amount of resources. It is obvious that a decision maker cannot make a healthy decision under this many considerations by himself/herself. Therefore, there is a need for a decision support model that examines the process systematically with evaluating all possible consequences with taking care of the decision maker's values and preferences at the same time in this kind of a situation.

So, we develop a methodology utilizing the benefits of Value Focused Thinking in order to specify the values of the decision maker for a given multi objective decision problem, and then moving it forward into a multicriteria decision making problem as a constraint and finding the optimality conditions for any given problem including the decision maker's values. Then, we demonstrate the usefulness of this methodology in the case study for Turkish Air Force Flying Hour Program.

Regarding the research questions stated in chapter 1, we see from the case study that this methodology is robust, effective and efficient when you have multiple conflicting objectives. We can include the decision maker's value structure and preferences in the model and visualize them by using software, which is simple to use and easy to reach like Microsoft Office Excel 2007. Using the add-in Hierarchy Builder Software Version 2.0 (Weir, 2008) in Excel for VFT, and then constructing an automated tool by the help of VBA for goal programming enables us to solve this complex problem in a short period of time. By doing this, we show that we can utilize some properties of VFT in a goal programming model efficiently. In this process, we work with the decision maker and SMEs, which means this methodology allows us to work with multiple decision makers. Instead of using pure mathematical formulations for the presentation of the method and results, the visual tool we create works better for the decision maker and SMEs to understand the structure of the problem and to interact with the analyst within the process rather than to be involved after obtaining the results.

From the methodology we create, we see that the goal constraints in the formulation do not need to be in linear relationships. They may be monotonically increasing or decreasing functions, which are nonlinear in VFT, but still useful for goal programming formulations to obtain optimum solutions.

One of the major concerns about goal programming is incommensurability as stated in chapter 2. If we recall this issue, the decision maker can have difficulty to define the goals for different types of variables like flying hours versus budget. Therefore, there are many techniques created to overcome this issue. However, our methodology shows that we can overcome this issue simply by using the benefits of SDVFs. In the VFT portion of the research, we scale all decision variables between 0 and 1 by using single dimensional value functions. Hence, it facilitates a better understanding of the trade-offs between decision variables for the decision maker, and excludes incommensurability from our concerns in the formulation process.

In addition to incommensurability, one of the other major concerns in goal programming is about weighting as we state in chapter 2. By looking at pure mathematical background of a goal programming formulation, the decision maker may have difficulty to understand the structure and weight the variables according to their importance. There is much research carried out to find an efficient technique for weighting in goal programming. However, our methodology makes it easier by utilizing the weighting techniques of VFT. In this research, we use the swing weight method for reasons stated in chapter 2, but there are many other techniques that can be utilized in the same manner. In VFT, the decision maker is involved in the process from the beginning where we start building the value hierarchy representing his/her values. Thus, it becomes easier for the decision maker to weight this visual tool created according to his/her own values. Moreover, it enables us to do some sensitivity analysis on weights to see how the system is sensitive to small changes.

5.3 Future Work

On the same decision problem or similar problems, the following research can be done for future work;

- Different multi criteria decision analysis methods can be applied for the methodology.
- Other solution algorithms, computer programs or software can be used to solve the problem faster.
- The robustness and efficiency of the methodology can be tested for other types of SDVFs (nonconvex, categorical etc.).

Appendix A. Value Hierarchy

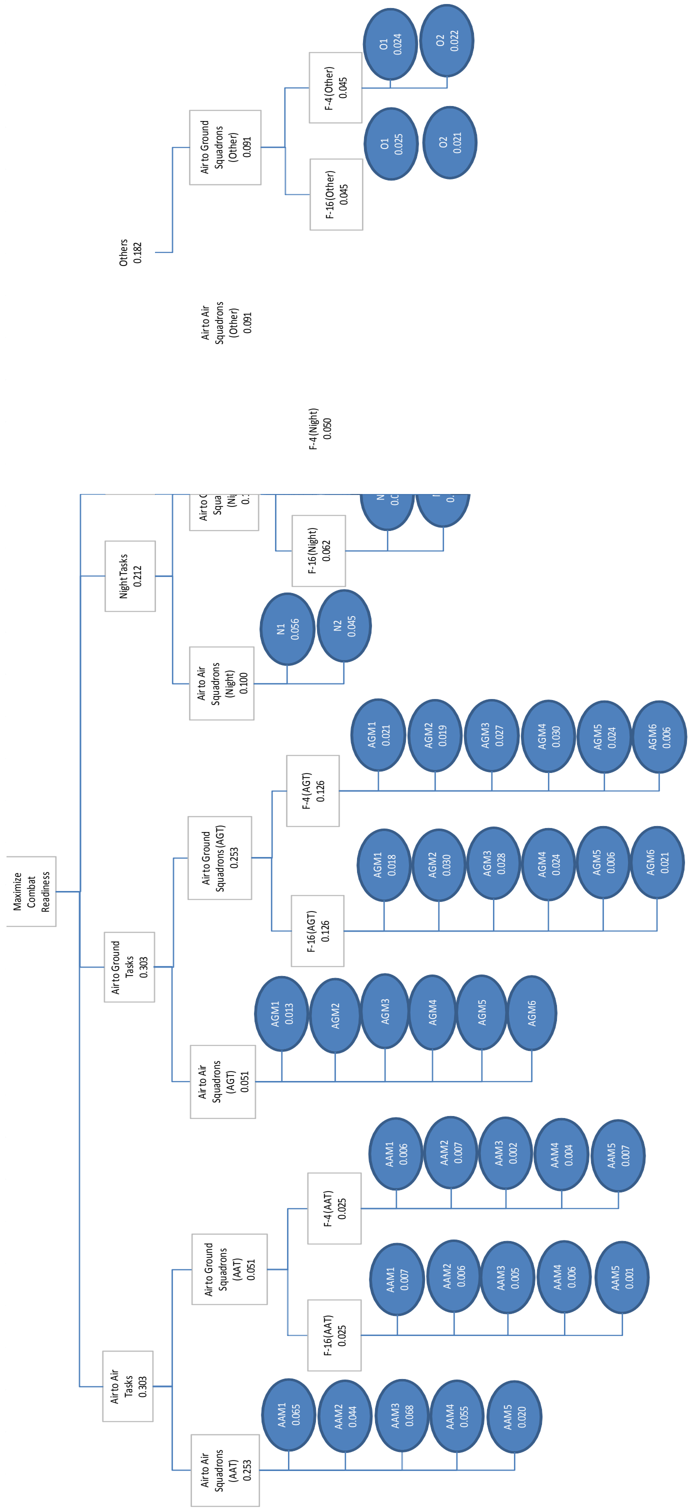


Figure A. 1 Value Hierarchy

Appendix B. VBA Code for Goal Programming

```
Public F4CostEntry As Currency
Public F16CostEntry As Currency
Public TotbudgetEntry As Currency
Public iterationEntry As Long
Public BinsEntry As Currency
Public Minbudget As Currency
Global rownumber As Integer
'*** uses userform.1 to get the values needed for the program ***
Public Sub UserInterface()
   UserForm1.Show
End Sub
'*** main program for building the sheet and solves data ***
Public Sub GoalProgramming()
Application.ScreenUpdating = False
'*** name the columns data for the goal programming formulation in hierarchy sheet
(sheet1) ***
   Dim Tnow
   Dim Tfin 'measures time (how long it takes for the program to finish
   Tnow = Now
   Count = 50000
   countvalues = 50000
   Sheets(1).Cells(countvalues - 1, 59) = "BELOW"
   Sheets(1).Cells(countvalues - 1, 60) = "MISSIONS"
   Sheets(1).Cells(countvalues - 1, 61) = "WEIGHTS"
   Sheets(1).Cells(countvalues - 1, 62) = "RHO"
   Sheets(1).Cells(countvalues - 1, 63) = "MIN"
   Sheets(1).Cells(countvalues - 1, 64) = "MAX"
'*** copy measures names and global weigths from the hierarchy sheet (sheet1) ***
   While Sheets(1).Cells(Count, 8) <> ""
      If Sheets(1).Cells(Count, 8) = "M" Then
         Sheets(1).Cells(Count, 1).Select
```

```
        Sheets(1).Cells(countvalues, 59) = Sheets(1).Cells(Count, 2)
        Sheets(1).Cells(countvalues, 60) = Sheets(1).Cells(Count, 1)
        Sheets(1).Cells(countvalues, 61) = Sheets(1).Cells(Count, 6)
        countvalues = countvalues + 1
      End If
    ScreenUpdating = True
      Count = Count + 1
    Wend
'*** take rho(A99) minimum (M14) and maximum (M15) values from each sheet for SDVFs , then copy data to a new sheet for Goal Programming ***
    Count = 50000
    countvalues = 50000
        ScreenUpdating = False
        Sheets(1).Visible = True
        Sheets(1).Activate
          For i = 8 To Worksheets.Count
            Sheets(i).Activate
            Range("M14,M15").Select
            Selection.Copy
            Sheets(1).Activate
            Sheets(1).Cells(countvalues, 63).Select
            Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone,
        SkipBlanks:=False, Transpose:=True
            Sheets(i).Activate
            Range("A99").Select
            Selection.Copy
            Sheets(1).Activate
            Sheets(1).Cells(countvalues, 62).Select
            ActiveSheet.Paste
            countvalues = countvalues + 1
            Visible = False
          Next i
```

```
    AddNewSheet        'creates new sheet for Goal Programming
    GetData            'copy data in the Hierarchy sheet (sheet1) to a new sheet for Goal
                       Programming
    ArrangeGP          'Arranges GP Formulation sheet
    SelectAirCraftType 'Determines the aircraft type, takes the costs, and writes its cost to
                       the corresponding cells for each mission
    NameRanges         'Gives names to the ranges for simplicity in calculation with solver
    UsingSolver        'Solves the problem using Excel Solver
    Simulation         'Run Solver 5000 times and record results into another sheet
    Analyze_Data       'Opens a new spreadsheet that shows us the data for analysis
    unhide_worksheets  'unhide the worksheets to see the results
    Tfin = Now - Tnow
    MsgBox Tfin, vbOKOnly, "Shows the time that the program ran."
   Application.ScreenUpdating = True
End Sub
'*** creates new sheet for Goal Programming ***
Sub AddNewSheet()
Application.ScreenUpdating = False
Sheets.Add after:=Sheets(Sheets.Count)
    Sheets(Sheets.Count).Select
    Sheets(Sheets.Count).Name = "Goal Programming"
End Sub
'*** copy data in the Hierarchy sheet (sheet1) to a new sheet for Goal Programming ***
Sub GetData()
Application.ScreenUpdating = False
Count = 50000
    countvalues = 50000
    Sheets(1).Activate
    Sheets(1).Cells(countvalues - 1, 59).CurrentRegion.Select
    Call ModifyRegion
    Selection.Copy
    Sheets("Goal Programming").Activate
```

```
    Range("A1").Select
    ActiveSheet.Paste
    Sheets(1).Activate
    Sheets(1).Cells(countvalues - 1, 59).CurrentRegion.Select
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    Selection.Borders(xlEdgeBottom).LineStyle = xlNone
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Selection.Borders(xlInsideHorizontal).LineStyle = xlNone
    ActiveWindow.ScrollWorkbookTabs Position:=xlLast
    Selection.ClearContents
    Sheets("Goal Programming").Select
End Sub
'*** Arranges GP Formulation sheet ***
Sub ArrangeGP()
Application.ScreenUpdating = False
    countvalues = 2
'*** Give Headings for Data ***
    Sheets("Goal Programming").Activate
    Sheets("Goal Programming").Cells(countvalues - 1, 7) = "TOTAL VALUE"
    Sheets("Goal Programming").Cells(countvalues - 1, 8) = "FUNCTION"
    Sheets("Goal Programming").Cells(countvalues - 1, 9) = "DEVIATION"
    Sheets("Goal Programming").Cells(countvalues - 1, 10) = "FLYING HOURS"
    Sheets("Goal Programming").Cells(countvalues - 1, 11) = "COST PER AIRCRAFT"
    Sheets("Goal Programming").Cells(countvalues - 1, 13) = "OBJECTIVE VALUE"
    Sheets("Goal Programming").Cells(countvalues + 1, 13) = "BUDGET LIMIT"
    Sheets("Goal Programming").Cells(countvalues + 1, 14) = "<="
    Sheets("Goal Programming").Cells(countvalues + 1, 15) = "TOTAL BUDGET"
    Sheets("Goal Programming").Cells(countvalues + 2, 14) = "<="
```

```
   Columns("A:Z").EntireColumn.AutoFit
'*** Writes the formulation for the exponential function ***
   Sheets("Goal Programming").Cells(countvalues, 8).Select
   ActiveCell.FormulaR1C1 = _
      "=(1-EXP(-(RC[2]-RC[-3])/RC[-4]))/(1-EXP(-(RC[-2]-RC[-3])/RC[-4]))"
   Sheets("Goal Programming").Cells(countvalues, 8).Select
   rownumber = ActiveSheet.Cells(1, 1).CurrentRegion.Rows.Count
   Selection.AutoFill Destination:=Range("H2:H" & rownumber), Type:=xlFillDefault
   Range("H2:H" & rownumber).Select
' here instead of putting deviation and flying hours as decision variables we only use flying hours
'*** ensures the sum of deviation and value is equal to the total value 1 ***
   Range("I2").Select
   ActiveCell.FormulaR1C1 = "=1-RC[-1]"
   Sheets("Goal Programming").Cells(2, 9).Select
   Selection.AutoFill Destination:=Range("i2:i" & rownumber)
End Sub
'*** Determines the aircraft type, takes the costs, and writes its cost to the corresponding cells for each mission ***
Public Sub SelectAirCraftType()
Application.ScreenUpdating = False
         AircraftRow = 2
         Sheets("Goal Programming").Activate
   Do While ActiveSheet.Cells(AircraftRow, 1) <> ""
      If Left(ActiveSheet.Cells(AircraftRow, 1), 3) = "Air" Then
         Sheets("Goal Programming").Cells(AircraftRow, 11).Value = F16CostEntry
         ElseIf Left(ActiveSheet.Cells(AircraftRow, 1), 3) = "F-1" Then
         Sheets("Goal Programming").Cells(AircraftRow, 11).Value = F16CostEntry
         Else: Sheets("Goal Programming").Cells(AircraftRow, 11).Value = F4CostEntry
      End If
          AircraftRow = AircraftRow + 1
   Loop
```

```
End Sub
'*** Gives names to the ranges for simplicity in calculation with solver ***
Sub NameRanges()
Application.ScreenUpdating = False
    Range("I2:I" & rownumber).Select
    Selection.Name = "DeviationVar"
    Range("J2:J" & rownumber).Select
    Selection.Name = "DecisionVar"
    Range("G2:G" & rownumber).Select
    Selection.Name = "TotalVal"
    Range("F2:F" & rownumber).Select
    Selection.Name = "MaxHours"
    Range("E2:E" & rownumber).Select
    Selection.Name = "MinHours"
    Range("C2:C" & rownumber).Select
    Selection.Name = "Weights"
    Range("M2").Select
    Selection.Name = "ObjectiveVal"
    ActiveCell.FormulaR1C1 = "=SUMPRODUCT(Weights,DeviationVar)"
    Range("K2:K" & rownumber).Select
    Selection.Name = "Cost"
    Range("M4").Select
    Selection.Name = "BudgetLimit"
    ActiveCell.FormulaR1C1 = "=SUMPRODUCT(DecisionVar,Cost)"
    '*** Starts the budget from the upper limit
    Range("DD2").Select
    ActiveCell.FormulaR1C1 = "=SUMPRODUCT(MaxHours,Cost)"
    TotbudgetEntry = Sheets("Goal Programming").Cells(2, 108).Value
    Sheets("Goal Programming").Cells(4, 15).Value = TotbudgetEntry
    Range("O4").Select
    Selection.Name = "TotalBudget"
'*** Arranges the Increments from the total budget according to the iteration entry
```

```
    Range("DD1").Select
    ActiveCell.FormulaR1C1 = "=SUMPRODUCT(MinHours,Cost)"
    Minbudget = Sheets("Goal Programming").Cells(1, 108).Value
    BinsEntry = (TotbudgetEntry - Minbudget) / iterationEntry
End Sub
'***  Solves the problem using Excel Solver ***
Public Sub UsingSolver()
   Application.ScreenUpdating = False
   Worksheets("Goal Programming").Activate

    ActiveSheet.Range("J2:J" & rownumber) = ActiveSheet.Range("E2:E" & rownumber)
    'to reset Solver and make sure we are solving this equation
    SolverReset
    'Setting objective function and decision variables
    SolverOK    SetCell:=Range("ObjectiveVal"),      MaxMinVal:=2,
            ByChange:=("DecisionVar")
    'Adding constraints to the problem
    SolverAdd   CellRef:=Range("BudgetLimit"),      Relation:=1,
            FormulaText:=Range("TotalBudget")
    SolverAdd   CellRef:=Range("DecisionVar"),      Relation:=1,
            FormulaText:=Range("MaxHours")
    SolverAdd   CellRef:=Range("DecisionVar"),      Relation:=3,
            FormulaText:=Range("MinHours")
    'Assuumptions of linearity and nonnegativity
    solveroptions AssumeLinear:=False, AssumeNonNeg:=True
    solveroptions Precision:=10 ^ -8
    solveroptions iterations:=3000
    solveroptions convergence:=10 ^ -5
    'Solve solver and ignore the solver results dialogbox appear
    SolverSolve UserFinish:=True
    '***Keep final solution of solver ***
    SolverFinish KeepFinal:=1 ', ReportArray:=Array(2)
    Application.ScreenUpdating = True
```

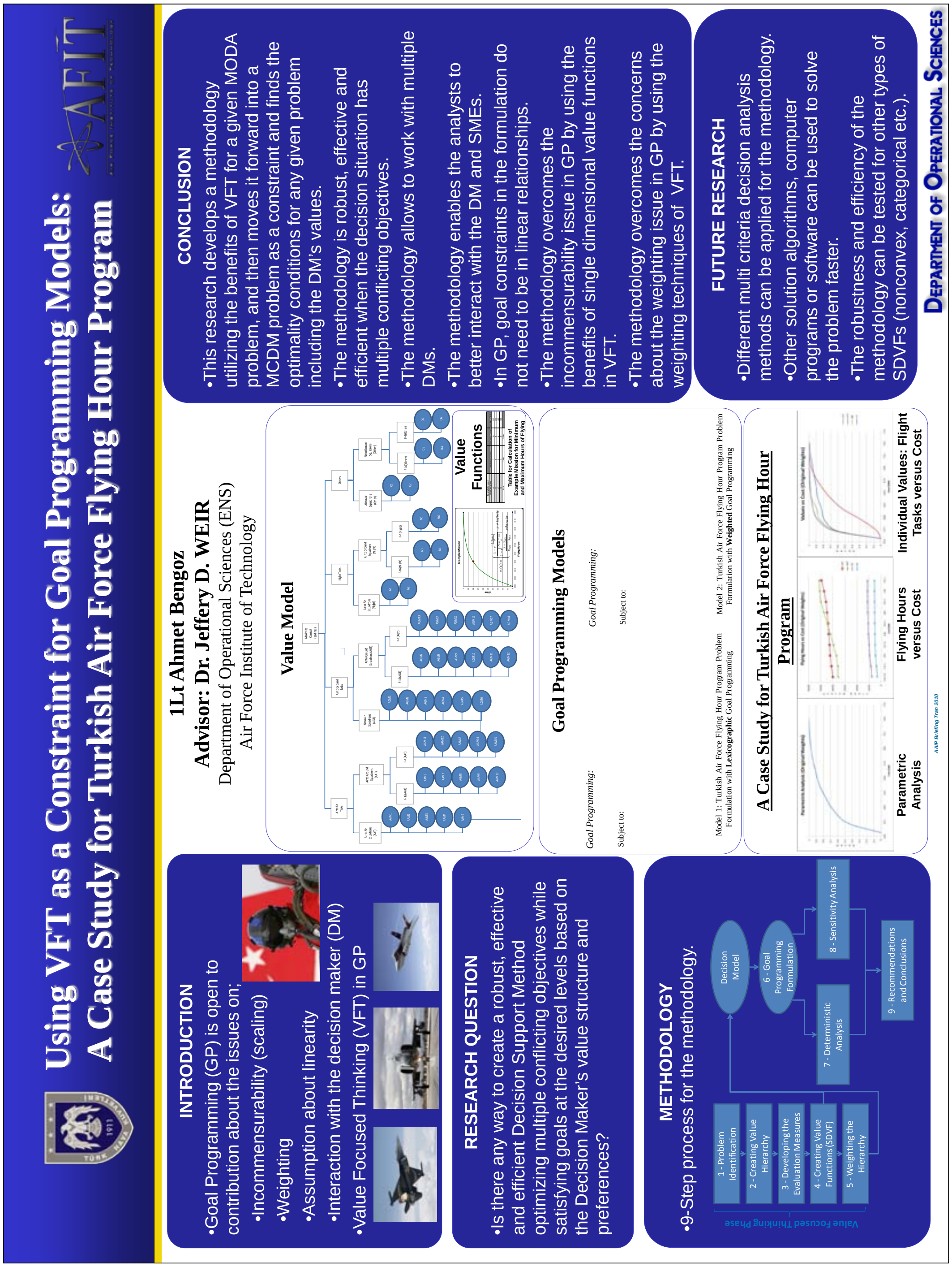
```
End Sub
'*** Run Solver "iterationEntry" times and record results to another sheet ***
Sub Simulation()
Dim i As Long
'*** creates new sheet for Simulation Results ***
    Sheets.Add after:=Sheets(Sheets.Count)
    Sheets(Sheets.Count).Select
    Sheets(Sheets.Count).Name = "Sim Results"
    Sheets("Sim Results").Select
    Sheets("Sim Results").Cells(1, 1) = "Values"
    Sheets("Sim Results").Cells(1, 2) = "Budget"
    Sheets("Goal Programming").Select
    Sheets("Goal Programming").Range("B2:B" & rownumber).Select
    Selection.Copy
    Sheets("Sim Results").Select
    Range("C1").Select
      Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone, SkipBlanks:= _
      False, Transpose:=True
Application.ScreenUpdating = False
  For i = 1 To iterationEntry
      Sheets("Goal Programming").Range("TotalBudget").Value = TotbudgetEntry - i *
BinsEntry
   UsingSolver
'*** copies decision variables (flying hours) after each run and writes it to records them
as results ***
    Range("DecisionVar").Select
    Selection.Copy
    Sheets("Sim Results").Select
    DoEvents
    Cells(i + 1, 3).Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
      :=False, Transpose:=True
```

```
'*** copies objective values after each run and writes it to records them as results ***
        Worksheets("Goal Programming").Activate
        Range("ObjectiveVal").Select
        Selection.Copy
        Sheets("Sim Results").Select
        DoEvents
        Cells(i + 1, 1).Select
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

'*** copies objective values after each run and writes it to records them as results ***
        Worksheets("Goal Programming").Activate
        Range("BudgetLimit").Select
        Selection.Copy
        Sheets("Sim Results").Select
        DoEvents
        Cells(i + 1, 2).Select
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False
        Worksheets("Goal Programming").Activate
        ClearContent
   Next i
   Sheets("Sim Results").Activate
End Sub
'*** deletes values from decision and deviation variables to initiate solver empty ***
Sub ClearContent()
    Range("J2:J" & rownumber).Select
    Selection.ClearContents
End Sub
'*** unhide the worksheets ***
Sub unhide_worksheets()
ActiveWindow.DisplayWorkbookTabs = True
```

```
    For i = 1 To ThisWorkbook.Worksheets.Count
        ThisWorkbook.Worksheets(i).Visible = True
    Next i
End Sub
```

Appendix C. Storyboard



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Vita

First Lieutenant Ahmet BENGOZ was born in Ankara, TURKEY. He completed his elementary, and secondary school educations in Ankara, TURKEY and attended the Maltepe Military High School in 1997. After graduation from military high school, he started his education in the Turkish Air Force Academy in 2001. He earned the degree of Bachelor of Science in Industrial Engineering in 2005. In the same year, he was assigned to Air Technical School for branch education as a supply officer. After this education, he was assigned to 8th Main Jet Base in 2006, and in 2007 he was assigned to 1st Main Jet Base as a supply officer. He entered Graduation School of Engineering and Management, Air Force Institute of Technology in 2010.

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14. ABSTRACT

In its 60-year history, there are many published documents in the literature for goal programming (GP), but it is still open to some contribution to the ones existed. Hence, this research is looking for a goal-programming model to achieve this effort by discussing one of the key assumptions of GP about linearity, and some issues about incommensurability (difference in data types) and weighting while formulating the problems. In addition, GP requires an interaction between the decision maker (DM) and analyst to ensure that the model reflects the DM's preferences. However, it may be hard to interact if the mathematical model is very large and complex including many decision and deviation variables in it. Hence, we want a model that makes easier to interact with the DM while converting his/her qualitative values into quantitative ones and visualize them to the DM.

Consequently, this research comes up with the idea of using value focused thinking (VFT) approach in order to overcome the issues mentioned in the previous paragraph by using it as a constraint in GP formulations. The use of model is demonstrated by a case study, "Turkish Air Force Flying Hour Program", which is a multi criteria optimization problem. It starts with utilizing the benefits of VFT in order to specify the values of the decision maker for a given multi objective decision problem, and then moves it forward into a multi criteria decision making problem as a constraint and finds the optimality conditions. The results obtained show the computational performance, efficiency, and robustness of the methodology.

15. SUBJECT TERMS
Multi Criteria Decision Analysis, Multi Objective Decision Analysis, Goal Programming, Value Focused Thinking, Decision Support Model, Air Force Flying Hour Program

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